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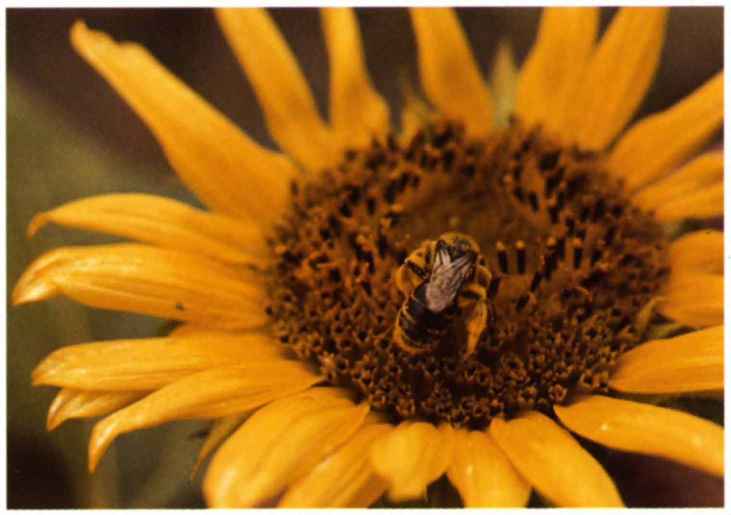

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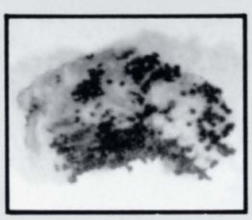

ABOUT THE COVER — PHOTOS COURTESY OF AUTHORS

Long awaited summer sun warms the Little Sahara Sand Dunes of Southern Utah, inviting cool winds, bare feet and dune buggies. So also do the jewel-like flowers emerge in summer's sun to attract the bees. The leafcutter bee is used for studies of sunflower pollination as well as for research seeking to control chalk brood disease.

PHOTO CAPTIONS

1. Large diameter perforated corrugated plastic drain tubing with a black plastic connector fitting.

2. Random fiber nylon synthetic drain envelope in place on a corrugated plastic drain tube prior to installation.

3. Gravel envelope material being loaded into a drain laying machine.

4. Corrugated plastic drain tubing being installed with gravel envelope material (California).

PHOTOS BY AUTHOR

DRAIN ENVELOPES

L. S. WILLARDSON

Investigation of drain envelope materials is one of the important research activities being conducted in the Utah Agricultural Experiment Station. The research is being done in the Department of Agricultural and Irrigation Engineering at Utah State University with the objective of improving drainage efficiency, reducing drain maintenance costs, and increasing the useful life of subsurface agricultural drains. Significant results have been obtained that will improve drain design and reduce long-term drainage costs. Both conventional and new synthetic materials are being investigated. A method has been found for determining when a drain envelope is necessary and what kind of envelope materials should be used.

The most common name applied to a drain envelope is filter, but that name is incorrect. There is a big difference between a filter and a drain envelope. If a filter is really working, it will clog up after some time. In contrast, envelope material around the drain physically holds the particles of soil back so that they do not move, and consequently, the soil does not get into the drain and clog it. Drain costs do increase when envelope materials are used around subsurface drains, but upkeep costs become negligible. A drain envelope works to hold the soil back and keep it from moving with the water. The few soil particles that may move generally will pass through the envelope material and pass out of the drain in the flowing water.

Most drains in the West and some drains in the East will not work properly without some kind of envelope material around the outside of the drain. The envelope material should be placed completely around the pipe to protect it from soil movement from all directions.

In the arid West, drains do not function well without envelope materials around them because the soils are structurally unstable when saturated and therefore erode easily. In the humid East, the soils are much more resistant to erosion and most drains can be installed without drain envelopes. Arid region soils are generally unstable because of their low organic matter content. If the soil around a drain erodes, the only place the soil particles can go is into the drain. The purpose of envelope materials under these conditions is to stabilize the soil next to the drain so that it does not erode.

Drain envelope research is not new. In the early 1900s, the U.S. Department of Agriculture published some bulletins on agricultural drainage.[1,2] The instructions in the bulletins suggested putting gravel around drains that were laid in unstable soils. The gravel accomplished two purposes; it gave a firm base at the bottom of the trench for the placement of the pipe, and it served as a drain envelope to keep the unstable soil from moving into the drain. One bulletin[2] even suggested wrapping the drain with cheesecloth or burlap to keep fine sand out.

The first subsurface drains in extensive use were made from short lengths of fired clay pipe. In later years, concrete pipe was used. Both kinds of pipe had flat ends that made simple butt joints. Irregularities in the pipe ends left spaces through which the water could enter. Since the water could only enter the pipe at its joints, it was easier for the water to get to the joints if the pipes were surrounded with a gravel envelope. When corrugated plastic pipes with multiple perforations became available, the need to have gravel around the pipe to help water flow along the outside of the pipe, was lessened. Since the plastic pipes were somewhat flexible, however, use of gravel also became important as a support for the pipes.

Plastic pipes also had another advantage besides their many perforations: they were much lighter in weight and so were easier to install. When heavy concrete and clay pipes were being used for drainage, the handling of heavy loads of gravel was not a special chore for the contractor. When the lightweight plastic pipes came into extensive use, the gravel became the heavy and expensive part of the job. Plastic pipe companies recognized a potential market for gravel envelope substitutes and began to develop synthetic fabric drain envelope materials. They first thought of the drain envelope as a filter and therefore wanted to sell materials that looked like filter cloth. Each company tried to find a material that had properties distinct from those of their competitor's materials.

As the number of synthetic envelope materials (or geotextiles as they are sometimes called) being proposed for use as drain envelopes increased, people wondered about differences in their performance in different soils. The Utah Agricultural Experiment Station helped fund a regional research project to define how the different fabrics worked. The Utah State Office of the Soil Conservation Service cooperated by providing information on locations of soils in the state that were known to have drain construction problems. Samples of those soils were obtained (Table 1), and a testing program was developed to find out how these soils responded to the different envelope materials. The soils varied from heavy clay to extremely unstable fine sand.

The research program soon showed that there were no significant differences between the envelope materials. Instead, it was the soils themselves that differed. Further testing with screens of precisely defined different sizes verified the earlier results (Table 2). Table 2 also mentions the Soil Hydraulic Failure Gradient (HFG), which is a measure of the soil stability or its strength and resistance to washing into the drain.

The two Utah soils on which the most tests were conducted were the St. George soil and the soil from Roosevelt. The St. George soil has an HFG of about 2.0 and the Roosevelt soil has an HFG of about 6.5, regardless of the size of screen used. Both of these values indicate a need for a drain envelope (see the following discussion of HFG). It is worthwhile noting that the material labeled screen in Table 2 is ordinary window screen, which gave results as good as did the special drain envelope fabrics.[4]

The results of the research showed that the important thing was to place an effective envelope completely around the drain, and that which material was used was not too important.

The research was extended to include soils from the humid areas of the United States. These soils and their texture types[3] are also shown in Table 1. The humid area soils had much higher hydraulic failure gradients than the Utah soils, which explains in part why drains can be installed in humid areas without drain envelopes.

After the fact of hydraulic failure gradient (HFG) had been established, it was found that the HFG was related to some commonly measured soil properties. Whenever a drainage system is designed, it is necessary to measure the hydraulic conductivity or permeability of the soil. The USU research showed that by adding one simple laboratory test, the test for Plasticity Index, PI, the HFG of the soil could be determined indirectly, thereby avoiding the difficult and expensive direct measurement laboratory tests that otherwise would be required. A simple equation was developed[3] to calculate hydraulic failure gradient:

Trencher installation of corrugated plastic drain tubing with a synthetic fabric envelope material (Utah).

HFG = EXP (0.332 − 11400K + 1.07ln PI)

where K is the hydraulic conductivity in meters per day, EXP is the power of e, ln is the natural logarithm, and PI is the plasticity index, and HFG is the hydraulic failure gradient.

If the HFG of a soil is above 50, the drain can probably be installed without an envelope. If the HFG is above 30, a synthetic envelope fabric can be used safely. If the HFG is below 30, the drain should be installed with a fine, naturally graded gravel or a coarse, naturally graded sand envelope material. The limiting HFG values suggested are approximate. When in doubt, use a gravel envelope. The specifications for gravel envelopes recommended by the Soil Conservation Service or the U.S. Bureau of Reclamation can be used to select a gravel envelope material for a particular soil. Coarse, single-sized gravels such as pea gravel should not be used because the soil washes through them.

The drain envelope research program at Utah State University is continuing its efforts to improve the diagnosis of drainage conditions so that drains can be installed with the assurance that they will function in a trouble-free manner for a long period.

TABLE 1. Textural classification of the soils*

Soil	Texture	Clay, %	Silt, %	Sand, %
Sterling†	Loam	15.4	48.5	36.1
Millville†	Loam	16.5	47.4	36.1
Jurek‡	Sand	5.6	2.9	91.5
Sebewa‡	Sandy loam	10.0	24.6	65.4
Keowns‡	Sandy loam	13.0	31.6	55.4
Capac‡	Loam	26.0	31.0	43.0
Brookston‡	Clay loam	35.4	36.1	28.3
Cache†	Silty clay	54.0	41.0	5.0
Roosevelt†	Clay loam	33.5	23.0	43.5
Delta†	Silty clay loam	30.0	61.0	9.0
St. George†	Sandy loam	0.0	41.5	58.5
Liberty sand§	Loamy sand	1.0	11.0	88.0

*According to the textural triangle used by the Bureau of Reclamation (1978)
†Utah soils
‡Michigan soils
§Ohio soil

TABLE 2. Failure gradients for soils against different envelope materials.

Material of Screen (1)	Opening in millimeters (2)	Soil; Hydraulic Failure Gradient: St. George[a] (3)	Richfield (4)	Roosevelt[b] (5)	Delta (6)	Cache (7)
None	—	P	—	0.8	—	—
8	2.360	—	—	6.90[c]	—	
Screen	1.6	2.4[c]	—	6.4	—	—
30	0.600	2.00	7.00	6.1[c]	3.5	3.0
60	0.250	2.6	—	6.8[c]	—	—
120	0.125	2.1	—	—	—	—
230	0.063	1.9	—	—	—	—
Drainguard	—	2.2	—	7.1	—	—
Typar	—	2.1[c]	—	6.2	—	—
Mirafi	—	2.7	—	—	—	—

[a]Maximum particle size = 0.124 mm.
[b]Maximum particle size = 0.1 mm.
[c]Test period longer than 24 hr.

Conclusions

Subsurface drains in arid areas should be installed with some kind of drain envelope material completely around the drain to prevent soil movement into the drain. The best envelope material is fine, naturally graded gravel or coarse, naturally graded sand. If the HFG of the soil is 30 to 50, synthetic fabric envelope material can be used. If the HFG of the soil exceeds 50, the drain can probably be installed without an envelope. Most arid region soils have low HFGs and require gravel envelopes that completely surround the drains.

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ABOUT THE AUTHOR

Lyman S. Willardson is a Professor in the Agricultural and Irrigation Engineering Department at USU. He received a BS and MS in Civil Engineering at USU and a PhD in agricultural engineering at Ohio State University.

W. F. CAMPBELL and
W. A. VARGA

TOUGH TURFS FOR UTAH

Turfs were developed by human beings to enhance their surroundings; the more technologically advanced people become, the more widely turfs are used. Today, turfs are vitally important in human activities from functional, recreational and aesthetic standpoints. The total area occupied by turfgrass species (lawns, estates, parks, golf courses, athletic fields and public grounds) is huge by any methods of estimating. Several states have indicated that the turf industry exceeds $150 million annually within their borders. This implies a conservative value approaching $4-5 billion in the United States as a whole.

The United States is generally subdivided into several turfgrass regions or zones of adaptation. These are: a) cool humid (North Central and North East sections of U.S. down to the Mason-Dixon Line), b) warm humid (southeastern U.S. below the Mason-Dixon Line), c) Great Plains (northern and southern), d) arid and semi-arid (Intermountain West—northern and southern), e) California coast and interior valleys, and f) North Pacific coastal regions (Sprague 1982). The turfgrasses, on the other hand, have been divided into only two groups, namely cool season and warm season species. Although there are hundreds of different species of grasses, only a few groups are adapted to production of turf in the cooler portions of the United States. The turfgrasses suited to cooler regions are generally satisfactory across the upper portion of the United States, but in the Northern Great Plains and the arid and semi-arid regions, irrigation is required to supplement the natural rainfall. The cool season grasses include bluegrasses, bentgrasses, fescues, and ryegrasses. Those suited to the warmer regions of the United States include bermudagrass, kikuygrass, bahiagrass, zoysia, St. Augustinegrass, buffalograss, sideoats grama, and blue grama.

A general comparison between cool season and warm season turfgrasses reveals distinct differences. The low growing, warm season turfgrasses are substantially more tolerant of close mowing; are deeper rooted, and are more drought, heat and wear tolerant as a group than the cool season turfgrasses. The former are less low temperature hardy, however, and will discolor at low temperatures. Ample evidence indicates that the growth and development of certain turfgrasses are restricted to a specific temperature range. Generally speaking, cool season and warm season turfgrass species have optimum temperatures of 15° to 24°C (59° to 75°F) and 26° to 32°C (78.8° to 89.6°F), respectively. This range varies considerably among turfgrass species, however, and among varieties within species. As temperatures are increased or decreased from its optimum range, growth of a grass is proportionally reduced until it ceases. Death may occur due to destruction of the protoplasm if the grass plants are subjected to increases or decreases in temperature beyond that point. There is relatively little biological activity in any grass above 52°C (125.6°F) or below 0°C (32°F). Turfgrass growth and development are usually confined to a temperature range of 5° to 41°C (41° to 105.8°F). Temperature regimes within this range then are a major factor influencing the adaptation of turfgrasses to particular areas.

Although Utah is located in the cool arid and semi-arid region, 'FuTurf,' bahiagrass, and 'Zoysia Z-52,' zoysiagrass, have been advocated as potential turfgrasses suited to the State's diverse growing conditions. Since both of these grasses are subtropical type grasses, it was anticipated that their intolerance to low temperatures would not allow their adaptation to northern Utah. It is this intolerance to low temperatures of these grasses in comparison to cool season grasses, that we wish to address in this paper.

Turf species, varieties, blends (different varieties of same species), and mixtures (different species) were established in the spring of 1980 by seeds or plugs (Figure 1) at the USU Farmington Field Station, Farmington, UT (Table 1). Evaluation and collection of data were not started until the 1982 growing season because Zoysia (established by plugs) did not 'heel-in' and provide a solid turf stand until the end of the 1981 growing season. The turfs were generally sprinkler irrigated weekly, however, both seasons were extremely wet and weekly irrigation was not needed early in the season. The fertilization program was approximately 0.45 kg N/100 m^2 (1 lb N/1000 ft^2), applied in the spring (usually around the first of April), the week before Memorial Day and Labor Day week-ends. The fertilizers used were 34-0-0 for the spring and 27-12-0 for the second and third applications. The turfs were generally mowed weekly.

In sharp contrast to the production of crops, where plant quality and yield are of major importance, turf production is exclusively designed to create an environment aesthetically suitable for recreation and relaxation. This creates problems in choosing quantitative measurements that can also be qualitatively interpreted, since the

PHOTOS BY AUTHORS

1. Zoysiagrass turf plot in early September of establishment year.

2. Overview of turf plots in late September. Note light color of subtropical grass plots. Also note the grassy weeds coming into the plots.

3. Overview of plots in early November of establishment year. Note the brownish color of FuTurf in middle plot and Zoysia in far plot.

4. Zoysiagrass turf plot in early May. Note the brown color of Zoysia and the invasion of grassy weeds.

5. FuTurf turf plot in early May. Note the brown color of FuTurf and the invasion of grassy weeds.

6. FuTurf turf plot in early May. Note the brown color of FuTurf and the invasion of grassy and broad-leaved weeds.

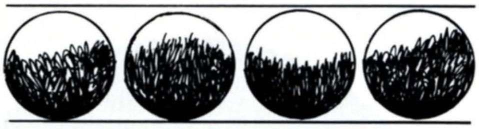

TABLE 1. Turfgrass species and varieties; used alone, in blends or in mixtures.

Plant Idnt. No.	Turfgrass Variety
1	Zoysia Z-52
2	FuTurf
3	Merion Kentucky Bluegrass
4	Lawn Mixture
	90% Kentucky Bluegrass (Common)
	10% White Clover (Dutch)
5	Magic Carpet
	33% Parade Kentucky Bluegrass
	33% Baron Kentucky Bluegrass
	33% Merion Kentucky Bluegrass
6	Patio N Shade
	50% Kentucky Bluegrass (Common)
	35% Citation Perennial Ryegrass
	15% Creeping Red Fescue
7	Common Kentucky Bluegrass
8	Park Kentucky Bluegrass
9	Family Brand Mixture
	40% Chewing Fescue
	28% Kentucky Bluegrass (Common)
	22% Victa Kentucky Bluegrass
	10% Pennlawn Fescue
10	Victa Kentucky Bluegrass
11	Creeping Red Fescue
12	Windsor Kentucky Bluegrass

evaluation of turf quality is highly subjective. What one observer may consider to be satisfactory turf conditions in a given area, another may deem inadequate. Turf quality is frequently evaluated using a subjective visual scale of 1 to 5 to measure the components of uniformity, density, texture, growth habit, smoothness and color. In July and August of both growing seasons, use of these components to evaluate the different turfs showed distinct differences between the subtropical Z-52 and FuTurf and the cool season varieties for uniformity, density, texture, smoothness and color. In both seasons that the turfs were evaluated, Z-52 and FuTurf did not 'green-up' until near the first of June and were the first to turn brown and go into dormancy following the first few cool (about 10°C) nights in September (Figures 2, 3, 4, 5, and 6). During July and August, when temperatures were warm these grasses exhibited sufficient color and uniformity as to make them pleasingly aesthetic.

At the end of both growing seasons (about Oct. 15), turfs were evaluated for weed infestation. Although both broadleaved and grassy weeds were present, they appeared more prevalent in the plots of the sub-tropical grasses (Figures 4, 5, and 6). Dandelion populations were especially heavy in the common Kentucky bluegrass, the lawn mixture, FuTurf and Z-52 plots. Field bindweed and malva also appeared in a few of the plots. Clumps of orchardgrass, barnyard grass, tall fescue and bentgrass appeared in many of the turfs. Bluegrass, however, was the most common grassy weed found in the FuTurf and Z-52 plots.

A dense, uniform, smooth, healthy, vigorously growing turf is a most pleasing, aesthetic sight, whether it is around a home, school, city park, or some other area. These traits of turf are best achieved by a monoculture, i.e., a single variety. A monoculture is, however, against nature, and in many turf areas broadleaved weeds and weed grasses become established. By definition a 'weed' is a plant growing where it is not wanted or essentially a plant out of place. People's attitudes determine which plants are not wanted in turfs and are, therefore, considered weeds. Turf specialists usually call a plant a weed when it disrupts the uniformity of a turf due to a substantially different leaf width and/or shape, growth habit or color. Frequently, turf managers

TABLE 2. Percent of broadleaved and grassy weeds in turf plots at the end of the growing season for 1982 and 1983.

	Broadleaf Weeds											
	Dandelion*		Field Bindweed		Malva		Oxalis		White Clover		Black Medic	
Turf Variety	82	83	82	83	82	83	82	83	82	83	82	83
Zoysia Z-52	22	25	0	0	3	4	0	0	1	1	0	0
FuTurf	18	20	0	0	3	4	1	1	0	0	0	0
Merion Ky. Bluegrass	6	7	5	5	1	1	0	0	1	1	0	0
Lawn Mixture	23	23	0	0	1	1	0	0	0	0	0	0
Magic Carpet	3	3	2	2	1	1	0	0	0	0	0	0
Patio N Shade	2	2	2	3	0	0	0	0	0	0	0	0
Common Ky. Bluegrass	13	13	0	0	1	1	0	0	0	0	0	0
Park Ky. Bluegrass	3	3	1	1	0	0	0	0	1	1	0	0
Family Brand Mixture	2	2	1	1	0	0	0	0	0	0	0	0
Victa Ky. Bluegrass	1	2	5	5	0	0	0	0	0	0	0	0
Creeping Red Fescue	5	5	2	2	0	0	0	0	1	1	0	0
Windsor Ky. Bluegrass	3	3	0	0	1	1	0	0	0	0	1	1

	Grassy Weeds									
	Blue Gr.		Orchard Gr.		Barnyard Gr.		Tall Fescue		Bentgrass	
Turf Variety	82	83	82	83	82	83	82	83	82	83
Zoysia Z-52	5	5	2	2	0	0	5	5	0	0
FuTurf	25	90	1	1	1	1	1	1	0	0
Merion Ky. Bluegrass	—	—	0	0	0	0	0	0	0	0
Lawn Mixture	—	—	0	0	0	0	0	0	0	0
Magic Carpet	—	—	0	0	1	1	1	1	0	0
Patio N Shade	—	—	0	0	0	0	0	0	0	0
Common Ky. Bluegrass	—	—	0	0	1	1	0	0	0	0
Park Ky. Bluegrass	—	—	0	0	0	0	0	0	0	0
Family Brand Mixture	—	—	0	0	0	0	0	0	0	0
Victa Ky. Bluegrass	—	—	1	1	0	0	0	0	0	0
Creeping Red Fescue	1	1	1	1	5	5	0	0	3	3
Windsor Ky. Bluegrass	—	—	0	0	0	0	0	0	0	0

will plant a mixture of grasses that are highly compatible to ensure sufficient competition for the weedy species. In our study, blends, mixtures and some of the individual varieties exhibited sufficient vigor to be competitive with the weedy species (Table 2). Weeds generally become a major problem in turf when the grass loses its vigor and can no longer compete with them. Many weed plant species thrive under conditions that are unfavorable for the grass. This appears to be the case with the two sub-tropical grasses, Z-52 and FuTurf, since they did not provide sufficient competition to the invading weedy species until the first of June and ceased to be competitive early in September. This does not, however, explain the weedy species present in the bluegrass plots. More frequent fertilization or a herbicidal program might have altered these turfs' responses.

Yield has been used extensively in evaluating turfgrasses even though it is very responsive to changes in factors such as temperature and water and nitrogen availability. This is amply illustrated by the dry weight data collected monthly from the turf plots in 1982 and 1983 (Table 3). The delayed growth of the two subtropical grasses showed the effect of cool temperatures in the spring (Figure 1). This delayed growth allowed the bluegrass and other weedy types, which are better adapted to these cool temperatures, to invade these plots. Although the FuTurf plots were heavily infested with bluegrass in 1982, sufficiently large areas of pure stand could be found for harvesting. In 1983, however, the bluegrass infestations were so severe that the plots were abandoned (Tables 2 and 3). Generally, there was a marked increase in dry weight the first harvest following the fertilizer application. The other varieties were so responsible to the nitrogen fertilizer, that perhaps a different fertilizer regime might produce different responses in the subtropical species.

Madison (1963) reported that slow growth and low yield may be obtained both from a weak turf and from a vigorous turf that responds to cool nights, drought, or other stress factors by husbanding photosynthate as stored reserves. Hence, without additional information, it may be unwise to use yield to compare results between experiments, and perhaps, also between varieties exhibiting different genetic responses to environmental stresses.

This report presents a two-year comparison of subtropical and cool season grasses grown under the arid and semi-arid region of northern Utah. The turfgrasses were managed as the average homeowner might manage their lawn, i.e., fertilized three times per year and irrigated and mowed weekly. As one might expect, turfgrasses adapted to the temperate zone did well and the subtropical ones were slow to emerge from their dormant state in the spring and readily went into dormancy in the fall. This constituted a growing season of about 90 days for these grasses. The reduced growing season allowed the invasion of broadleaved and grassy weeds, thereby, detracting from the aesthetic value of these grasses. More frequent fertilization or a herbicidal program would probably benefit these subtropical varieties. Varieties, Merion, Park, Victa and Windsor Kentucky bluegrasses, the blend, Magic Carpet and mixtures, Patio N Shade and Family Brand Mixture all did well and can provide an aesthetic scene for the Utah homeowner. Patio N Shade and Family Brand Mixture should also do well in city parks, golf courses and athletic fields.

TABLE 3. Dry weight (gms) of turf varieties (30 x 30 cm).

		Dry Weight (gm)						
Variety	**Year**	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**
Zoysia Z-52	82			6.3	3.2	3.6	4.1	6.7
	83			5.5	3.3	4.9	3.3	5.3
FuTurf	82			2.3	7.9	5.2	3.4	7.7
	83			0.0	0.0	0.0	0.0	0.0
Merion Ky. Bluegr.	82	4.1	3.0	9.3	5.6	4.3	4.0	7.4
	83	5.0	4.8	6.5	5.0	6.8	5.9	5.4
Lawn Mixture	82	4.3	6.2	8.8	5.1	6.2	7.8	8.8
	83	5.3	4.3	7.3	5.4	6.6	5.7	6.0
Magic Carpet	82	3.9	2.2	7.6	3.9	3.4	4.7	6.1
	83	5.0	4.4	5.1	4.5	5.5	6.5	5.0
Patio N Shade	82	3.9	3.0	10.9	4.3	5.2	4.1	9.0
	83	6.9	6.4	6.8	5.7	6.2	6.8	6.2
Common Ky. Bluegr.	82	3.7	4.7	9.6	4.3	5.4	6.8	8.0
	83	6.1	4.2	6.6	6.5	4.4	5.6	6.9
Park Ky. Bluegr.	82	3.6	4.4	7.7	4.4	5.1	5.7	8.1
	83	4.6	4.3	6.8	5.6	5.1	5.8	5.5
Family Brand Mix	82	5.3	4.0	7.4	4.0	4.6	4.4	7.3
	83	5.9	6.4	5.5	5.1	5.6	5.6	4.9
Victa Ky. Bluegr.	82	2.8	1.6	6.5	5.0	3.3	5.2	5.6
	83	3.5	3.6	5.0	4.7	5.0	5.8	5.0
Creeping Red Fescue	82	4.6	3.8	9.2	3.9	5.6	4.9	10.5
	83	8.9	7.2	6.7	6.3	6.1	6.6	5.8
Merion Ky. Bluegr.	82	3.7	2.5	7.6	3.8	4.3	6.1	5.4
	83	5.7	3.9	5.2	5.1	2.9	3.7	4.9

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ABOUT THE AUTHORS

William F. Campbell is a professor of Agronomy with the Plant Science Department, USU. His training has been in agronomy, plant physiology, radiation botany, and cytology, with extensive experience in electron microscopy. His research interests include cytochemical, physiological, and ultrastructural responses of plants to environmental stresses.

William A. Varga is a research associate in the Plant Science Department, and directs horticultural research efforts at the display gardens at the Farmington Research Unit of the Experiment Station. He is a landscape garden consultant and is writing a weekly column on home gardening for *The Deseret News*.

PHOTOS

1. *Female of* ***Melissodes agilis*** *gathering pollen and nectar.*
2. *A sunflower head dusted with dye. When bees land they get dye on them which comes off on other heads. At night the dye is easily seen with ultra-violet light. Studies such as these enables researchers to "follow" bee movements in the field.*
3. *A sunflower bee egg (**Nomia**) on a pollen ball.*
4. *Close-up view of an* ***Andrena helianthi*** *larve in its cell.*
5. *Depth of cells of* ***Andrena helianthi*** *in a sunflower field.*
6. *Natural nest entrances of* ***Diadasia enavata.***
7. *A shelter for holding nesting media to house alfalfa leafcutting bees. The city of Hyde Park, Utah, is shown in the background.*
8. *Seeds are extracted in a spiral pattern for sampling in order to determine seed set.*
9. *Female of* ***Eumegachile pugnata*** *on flower in greenhouse. This bee is called the sunflower leafcutter bee.*
10. *Female of* ***Diadasia enavata*** *on cosmos.*
11. *Female of* ***Andrena helianthi*** *gathering pollen and nectar. Note pollen already gathered on hind legs.*
12. *An ambush bug. These insects hide in the flowers and capture, kill and eat, bees collecting pollen and nectar.*

PHOTOS BY FRANK PARKER

Tracking The Sunflower Bees...

L. M. BROWN and F. D. PARKER[1]

The cultivated sunflower (*Helianthus annuus v. macrocarpus* (D.C.) (Ck11)) is one of the four most important annual oilseed crops grown in the United States. Since 1972, total acreage planted as well as diversity of consumer use has increased significantly. Total plantings of sunflower in 1979 in the United States exceeded 5 million acres, with production value exceeding a half a billion dollars.

Sunflower has become one of the world's most important suppliers of vegetable oils.

Numerous studies of the science and technology of raising sunflowers have been published, but pollination, a key factor in seed production, has received little attention. Perhaps as a result, plant breeders in the United States now rely on self-fertile lines, even though insect-pollinated varieties out-produce self-pollinating varieties.

The reasons given for using the self-pollinated variety for pollination instead of the insect-pollinated variety is that a crop will still be produced even if the self-fertile hybrid is inadequate. If insects are scarce for pollination because of insecticides used for pest control or

[1]USDA, ARS Bee Biology and Systematics Laboratory, UMC 53, USU, Logan, UT 84322.

for some other reason, self-pollination would be the only answer. But under favorable circumstances the possibilities for insect-pollination are encouraging.

Recent studies reveal that a large majority of our native plants depend solely on one or more native insects for the pollination necessary for plant regeneration, bees being considered one of the most efficient pollinators.

It has been estimated that in the United States the value of some 90 crops that depend on insect pollination for maximum yield is $22 billion per year. If seeds of insect-pollinated forage plants for livestock are included, about a third of the nation's food supply depends directly or indirectly on pollination by insects, mainly bees. It is reasonable to assume that solitary bees account for at least half of this crop-pollination activity in the United States and perhaps more in areas where beekeeping is less prevalent.

Scientists at the USDA Bee Laboratory in Logan, Utah, have many goals. They identify and study native wild bee pollinators, recording their basic life histories, observing their habits and habitats, also making a study of their parasites and predators to determine the best way to eliminate them. They try to determine how climatic conditions affect the behavior of bees, finding out as much as possible about each visitor to a plant, so they can concentrate on the best species for future intensive study and possible use for pollination.

Bees are the most efficient and effective of all pollinators of plants because of their abundance, their rapid flight, and their tendency to visit several flowers of the same species in succession. Other contributing factors are their need for large quantities of nectar and pollen and their specialized hairs, which can trap and hold many pollen grains per bee.

The over 20,000 species of bees in the world outnumber species of birds and fish combined. The best known, the honey bee (*Apis mellifera*), is called a social bee because it lives in hives, housing one queen, workers and drones.

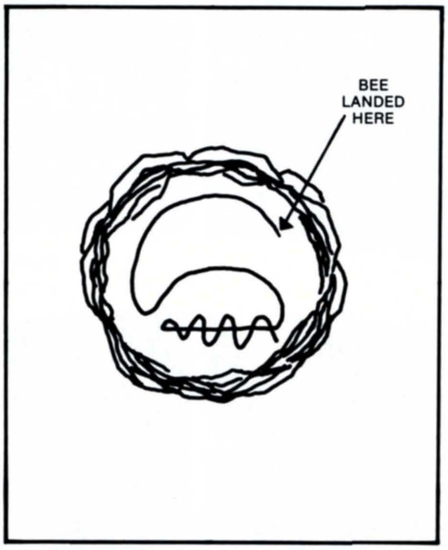

FIGURE 13.
Map of "bee landing" on heads of male sterile sunflower.

The honey bee is an imported bee and is the only bee presently managed for commercial pollination of oil-seed sunflowers in the United States.

In comparison to the honey bee, the female solitary bee independently mates, makes her own nest of about 10 brood cells, stocks the cells with food for the young, lays an egg in each cell and dies before the next generation emerges. The nest and brood cells of most solitary bees are made underground.

Bees apparently evolved about 100 million years ago, when flowering plants became the dominant vegetation on the earth. Archaeological and written evidence prove that the sunflower is a native North American crop—with which many native bees probably co-evolved. North American Indians found the sunflower seed a rich source of food. They also discovered medicinal uses for sunflower plant and paid homage to it in religious ceremonies.

The white settlers of America neglected the sunflower as a crop, although it extended over a wide area of the United States and into eastern Canada. Despite such neglect, some of the same types grown then seem to have survived into the present era. Early Spanish explorers probably introduced the sunflower to Europe. It was used in Europe first as an ornamental horticultural plant and second as a plant to provide food. It is believed that Peter the Great introduced the sunflower to Russia in the 18th century. Its cultivation spread rapidly because of its use as a source of oil. It became a major agricultural crop in Russia. The USSR remains the largest producer of sunflowers in Europe in this century. Records indicate that in about 1880 American farmers started ordering sunflowers from Russia and so it was re-introduced into North America.

Because of the possibilities of the further development of the sunflower as an agricultural boon economically in the United States, a scientist at the Logan laboratory has experimented since 1976 with sunflowers to identify suitable bees for its pollination. Even though honey bees are at present the only bee being managed for sunflower pollination in the United States, the experiments in Logan have shown that the honey bee is actually one of the least efficient pollinators of the sunflower, because they do not visit the pollen rows frequently, and they carry less pollen on their body hair than do female native bees. The amount of pollen carried on some sunflower bees seems incredible. One species, *Diadasia enavata*, carries more than a million grains per bee.

Honey bees were observed grooming the sunflower pollen from their bodies. It was also determined that plants visited by honey bees and bumble bees produced fewer seeds than those pollinated by native bees. Honey bees were not as numerous as native bees; they came during the first third of the blooming season and later in the day, usually around 11:00 a.m., after pollen was scarce.

Some native bees were present as soon as bloom began and they stayed with the sunflower plants until blooming ceased. This is essential if a pollinator is to be managed economically. Most bees of all kinds landed on the outer ring of the flowers, moved to the inner ring where there was pollen, and flew from there to the outer ring of another plant. This is important for maximum cross-pollination. Pollen was abundant very early in the day, and many native bees came even before sunrise. There were more bees of all types at 9:00 a.m. than at any other time of day. By midday most of the nectar had been removed from plants by the various insects.

Numbers of native bees increased each year of the experiments. By the third season several species were nesting within the plot and in areas adjacent to it. The scientists at the Logan laboratory concentrated on three native bees that are especially attracted to sunflower: *Melissodes agilis* Cresson, a groundnesting member of the Anthophoridae, *Andrena helianthi* Robertson and *Eumegachile pugnata* (Say), a large leafcutter bee.

The most frequently observed native bee on sunflower blooms was *M. agilis*. This species is probably valuable as an "unseen" pollinator (because of its ground nesting) where minimum or no-tillage agricultural practices are appropriate. It nested in and between irrigation furrows. Both male and female *Melissodes* are important sunflower pollinators because they are numerous and they carry many pollen grains on their bodies. Males carry about the same amount of pollen as the honey bee, but they spread it more because they continually fly over the flowers instead of the nesting sites searching for females (they even try to mate with the honey bees). Sixty-four percent of the *Melissodes* males' visits to flower heads lasted longer than one second. Also, the males clustered at night on the flower heads, sleeping in partially opened heads under the large ray petals.

Female *Melissodes* are more abundant on flowers early in the day. At 9:00 a.m. there were twice as many females present as at 11:00 a.m., and at 1:00 p.m. one third as many females were present as at 11:00 a.m. Most females remained in their nests in the afternoon. They provision their nests exclusively with sunflower pollen. The maximum pollen load carried by a female *M. agilis* was estimated at 330,000 grains (estimated by washing the pollen from the body hairs and counting the pollen grains with a haemocytometer).

Some of the nests of *M. agilis* were parasitized by the cuckoo bee, *Triepeolus helianthi* (Robertson). The cuckoo bee invades host nests in the

FIGURE 14.
Number of sunflower seed produced by the plant after a single visit by a* Melissodes *female. Good seeds are the larger ones at the center.

mornings when hosts are out.

Andrenid bees are one of the largest groups of North American Aculeates, but their biology is poorly known. Many *A. helianthi* were found in the sunflower plot at North Logan. They are also a ground-nesting bee. Adult females were found nesting between irrigation furrows in plots planted to sunflower. Their nests were scattered among the rows and the nest entrances were usually near sunflower stalks. Flowers pollinated by *A. helianthi* and *M. agilis* females produced a higher number of seeds than those pollinated by any other bee. *A. helianthi* nests consisted of a main burrow but few cells. Their nests were parasitized by another cuckoo bee, *Nomada*.

Eumegachile pugnata (Say) is one of our largest leafcutting bees. It occurs naturally throughout the sunflower growing regions. One advantage of this bee is that it will nest gregariously in artificial domiciles. Unlike most other leafcutter bees, females do not line the provisioned cells with leaf pieces; instead, they combine mud, leaf parts, and pulp to form thick plugs to separate cells. The egg is deposited at the top of the nest provision. *E. pugnata* females usually provision one cell a day.

The number of flowers that produced seed following a single visit by a female *E. pugnata* was higher than for males and much higher than for honey bees, although the visits by the female *E. pugnata* lasted a much shorter time.

Larvae of parasitic bees and predatory beetles were found in natural nests, but when the bee cells were individually screened before release, pests and disease had not generated any major problems.

Because of difficulties in managing a ground-nesting bee, it is believed that the best candidate for management for pollination of the sunflower at this time is the *E. pugnata*. Overwintering populations could be stored, incubated and released in synchrony with sunflower bloom. Bees could be trapped and transported from field to field during sunflower bloom. Movement of housing did not disturb this type of bee.

There are not enough honey bee colonies in the United States to meet any future demand for pollinators if fewer self-fertile lines of sunflower were used. No one has as yet tried to manage populations of any native bee for sunflower pollination in commercial fields; it is essential that a suitable native bee be found if we are to maximize sunflower production in the United States.

Several of the species of native bees observed visiting sunflower in the plot at North Logan have been reported to visit sunflowers at many other locations throughout the United States, southern Canada and northern Mexico. An exchange of information is needed to increase knowledge about the biology and possible utilization of native bees as potential pollinators of sunflower.

ABOUT THE AUTHORS

Louise Martin Brown is a graduate of the University of Georgia School of Journalism and is a free-lance writer. Her most recent stories have appeared in *The Herald Journal* and *The Deseret News*. She is presently employed at the USDA, ARS, Bee Biology and Systematics Laboratory.

Frank D. Parker has been the Research Leader at the USDA, ARS, Bee Biology and Systematics Laboratory since 1971. He is also an adjunct professor in the department of Biology at Utah State University. His primary interests are alfalfa and sunflower pollination, systematics and biology of native bees.

T. D. CHAAR

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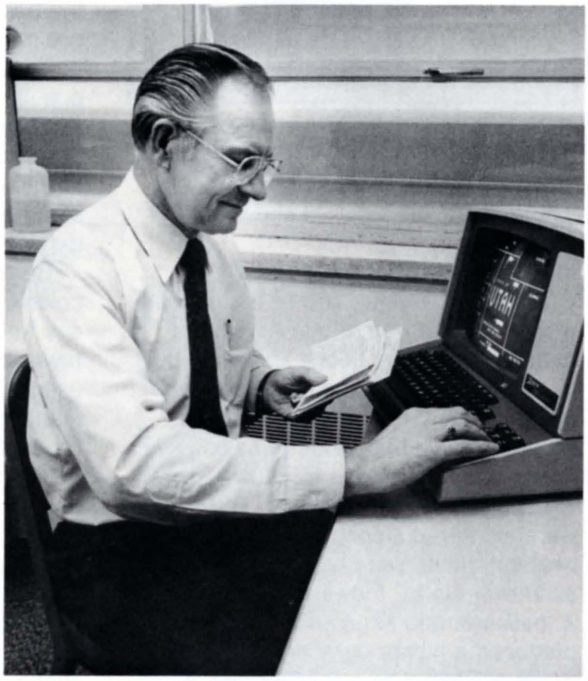

PHOTOS BY CEDRIC N. CHATTERLEY

PHOTO CAPTIONS

Dr. Gaylen L. Ashcroft, assistant state climatologist, extracts data from the computer for publication in a weekly summary report.

Dr. Gail E. Bingham, the new Utah state climatologist, inputs data into the computer for climate research he conducts with NOAA.

The staff of the State Climatologist Office, located at Utah State University, collects and stores weather records and analyzes, summarizes and makes the weather data available to the public in formats that are needed for input to private industry, agriculture, and governmental agencies. There is also a responsibility to determine climatic trends and to research how the weather and climate affects plants, animals, humans and our activities such as construction, production, transportation, recreation, etc.

Arlo Richardson has retired as State Climatologist after 22 years in that position carrying out the functions of the archiving, researching, analyzing, and extending the data to the public. Richardson has run standard analysis and has developed many unique analytical techinques. His equation for using climatic data to mathematically predict the growth and development of plants and insects has received worldwide acclaim. He has extended his information by teaching diverse groups ranging from training sessions of farmers to presentations of papers to scientific societies. He has left a wealth of records, graphs, tables, and other analyzed data necessary to answer the wide range of information requests that come to the office.

New State Climatologist

Gail Bingham, a graduate of Utah State University in Biometeorology, filled the position of Utah State Climatologist after Richardson's retirement. His main goal is to stay active in research. He insures that the state weather records are kept current and dispersed to the right individuals or agencies assisted by Gaylen Ashcroft, assistant climatologist, and Donna Crowell, staff assistant.

TOLOGY OFFICE

Bingham's research activity involves collection of atmospheric carbon dioxide data for long-term modeling of climate change due to the Greenhouse effect. This knowledge is important to all of us because a change in atmospheric carbon dioxide could, in time, lead to significant changes in world climate.To collect his data, Bingham flies on a NOAA (National Oceanic and Atmospheric Administration) aircraft twice a year manning a CO_2 sensor which he built to measure carbon dioxide exchange rates of large areas of the world.

The State Climatology Office Staff maintains a cooperative agreement with NOAA to compile and distribute state weather data to all interested parties. Within this agreement, the staff provides the following services: maintains over 175 data sources, prints a "Weekly Climate Update," compiles the climatic information for the USDA's weekly "Utah Weather, Crops, and Livestock," answers approximately 2,000 major public data requests per year, cooperates with state and federal researchers by providing and interpreting climatic data for their special needs, and publishes or helps publish pertinent weather summary information in books such as the "Utah Hydrologic Atlas," "Atlas of Utah," and "Utah Weather Guide."

While Bingham's function is in research, most of the recording of data is directed by Ashcroft.

With his duties of preparing weekly summaries of Utah's weather, Ashcroft oversees that the raw data are provided for the customers in a utilizable form. For example, in the winter, customers want to know about snow loads and in the summer they want to know about evaporation for design of sewage lagoons, and, in Utah, precipitation is always of interest.

Future Plans of the Climatology Office

Future directions of the State Climatology Office are to increase the services to the state's climatic data users, and to develop the necessary support to cover these services.

The State Climatology Office has data for about 200 stations, some of which go back more than 80 years. Most of these data are in printed form but we are now in an electronic age. User groups want the data accessible by computer. The new personnel are moving forward to create a machine-readable data base that can, for a small charge, be available through a telephone line by anyone in the world who has a microcomputer. Station histories and indexes to the stations would also be provided. Utility programs for averages and other standard analysis would be developed and put directly on-line in the universities' computer.

They are also in the process of developing the capability to write station data in a variety of microcomputer disc formats which would provide an alternative to modem transfer to off campus users and university researchers.

The office's current data base contains primarily precipitation and daily maximum and minimum temperature data. It is now giving high priority to extending the data base to include additional variables (wind, radiation, soil moisture, and water vapor), data measurement and collection services, and data applications and modeling.

Given an accurate, accessible data base, the office can supply services that were impossible to provide previously and they also plan to become the local public interface to providing state users with the models and scheduling services developed by other state researchers.

ABOUT THE STAFF

Gail Bingham was one of the first of two 1968 graduates in Biometeorology from Utah State University. He received his MS in thermal mechanics and PhD in Micrometeorology at Cornell University. As a commissioned officer in the U.S. Army, he spent two years studying atmospheric effects on laser beams with the U.S. Army Ballistics Research Laboratories at Aberdeen Proving Grounds in Maryland. On discharge from the military service, he was employed as an Environment Scientist at the University of California, Livermore, California. There he built 40 fast-response methane, ethane sensors to test the spread of natural gas after a simulated LNG tanker accident. From that stemmed an aircraft CO_2 sensor which is used for taking remote measurements of the carbon dioxide exchange rates of large areas of the world. In 1983, he became the Utah State Climatologist.

Gaylen Ashcroft obtained a BS and MS degrees in Soils from Utah State University. He received his PhD at Oregon State University with training in soils and meteorology, and has done research on the interaction of atmosphere and soil water on plant growth and development. While at USU, Ashcroft has authored three text books. He was appointed Assistant State Climatologist in 1982.

Donna Crowell, Staff Assistant, graduated from Utah State University with a BS in Business Education in 1974. Her duties are to organize and file climate data, update weather data into the computer, correct problems and assist in writing reports and radio broadcasts, screen data requests answering the questions within her technical ability, assist news media by collecting, processing and organizing information for presentation, and perform general secretarial functions.

ABOUT THE AUTHOR

Thaya Davis Chaar is the Acting Editor of the Utah Agricultural Experiment Station Publications Office (UAES).

The Little Sahara

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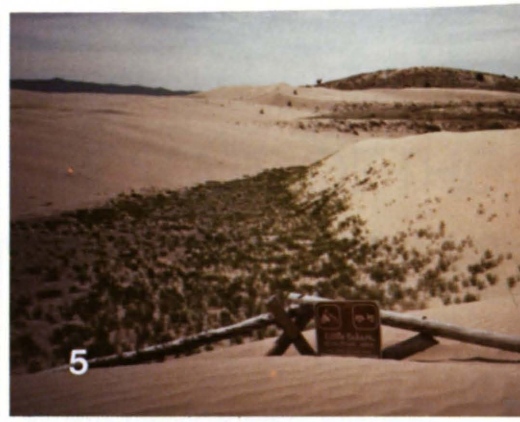

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PHOTOS by the AUTHORS
Black and White Figures 1, 4, 18, and 20, are located on pages 48-51.

2. Little Sahara dunes northwest of Sand Mountain. Note the lee-side deposits of falling dunes and parabolic dunes in the middle distance.

3. Juniper trees are alternately buried and exposed by shifting sand near the White Sands area.

5. Restricted motorized vehicle area vegetated with rhizomatous legume species, psoralea, near Jericho picnic grounds. Interaction of plants and dune communities.

6. ...and individuals.

7. The leading edges of wind gusts are active regions of suspension of dust.

8. Dust storms are often shallow, but transport dust over miles.

9. Surface sand ripples have formed on coalesced barchan dunes.

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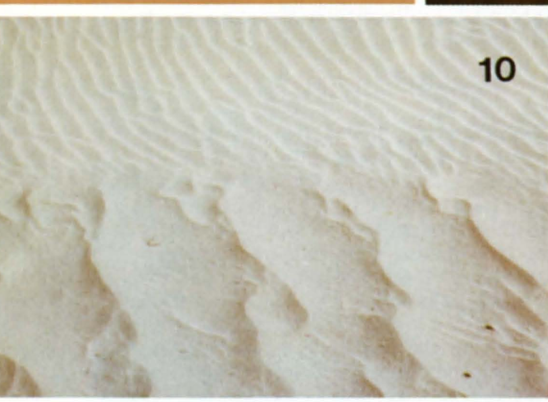

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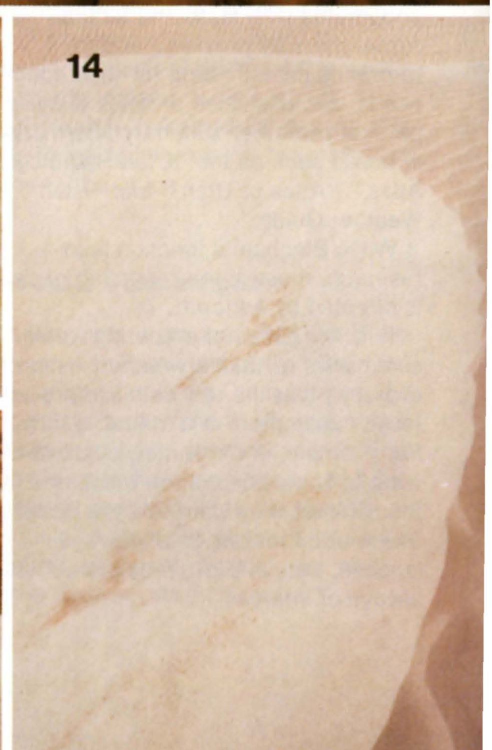

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10. Ripples are sensitive to sand grain size and wind speed...

11. ...and to local disturbances.

12. Sand Mountain, Nevada, formed in the stagnation zone windward of a ridge.

13. Sand and wind separate from the crest of a dune...

14. ...leaving light sediments on the slip face.

15. Slip faces avalanche when sand deposits become too steep.

16. Avalanching is enhanced by vehicle loads...

17. ...or even the weight of an insect.

19. Approach to Sand Mountain Area with vegetation on the lee slopes. Heavy use areas are strongly disturbed (by foot and motorbike).

21. Dune buggy used in maintenance of the fences covered by drifting sand.

Little Sahara represents the largest accumulation of active sand dunes in the state of Utah. Over one hundred thousand people visit the dunes annually. This combination of moving dunes and management for thousands of users has raised several issues of concern. One of these problems is to determine what effects people have on sand dune movement. If the effect is appreciable, then it is important to identify the management policies that might be beneficial for continuing use.

Description of Little Sahara

Little Sahara is located within the Basin and Range province in West-Central Utah. It is bounded on the south by Delta and Lynndyl and on the north by the Tintic Valley Research Station (Figure 1). The dunes (Figure 2) cover 140 square miles of which approximately 100 are included in a specially managed Bureau of Land Management (BLM) recreation area. The local topography slopes gradually to the north with elevations ranging between 4800-5200 feet above mean sea level. Small ridges composed of sedimentary and metamorphic rock are distributed throughout the dunefield, and these along with vegetation pose natural obstacles for the drifting sand. Sagebrush, grasses and juniper are among the common species found here with annual flowering plants adding a variety of color to the scene. From simple observations of the dunefield, it is obvious that these trees and plants are being alternately buried and uncovered by the sand (Figure 3).

The sand dunes are comprised primarily of fine, rounded quartz grains with inclusions of several other minerals. The fine polished nature of the individual grains points to aeolian transport. Prevailing wind direction from the south-southwest has combined with factors of vegetation and topography to influence the present configuration of the dunefield. The most likely source of sandy sediments for Little Sahara lies 15-30 km to the south where the Sevier River formed a delta into Lake Bonneville in pleistocene times. These deltaic deposits have subsequently been exposed to a drier climate following the retreat of Lake Bonneville. What were once alluvial deposits in the vicinity of Lynndyl have been sorted and rounded by aeolian processes, and transported to their present location as sand dunes.

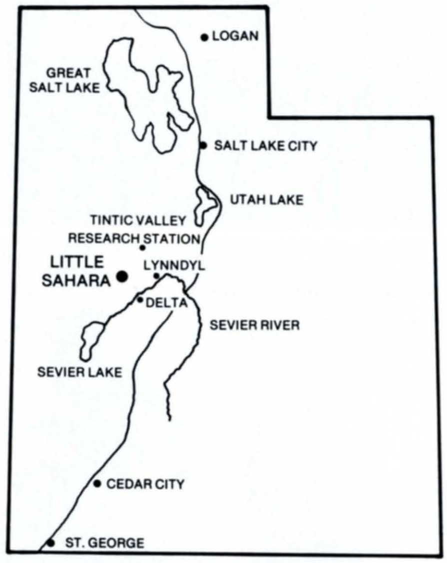

FIGURE 1.
Location of Little Sahara Recreation Area.

Management and Historical Use

The BLM assumed control of these public lands following the Taylor Grazing Act of 1935. Earlier mention of sand dunes in this area was made during geographic surveys of the state in the 1880s. A survey party with the Simpson Expedition refers to "Sand Hills" on their maps of the region. Historically, the use at the sand dunes has consisted of local recreation and wood gathering. The juniper trees that are scattered along the hills at the northwest perimeter of the dunes have been used as home-heating fuel. Horseback riding, hiking, and limited motorized recreational pursuits have also played a role in the history of this area.

Currently, Little Sahara is recognized as one of the most important off-road vehicle areas in Utah. The BLM responded to increased use during the past decade, particularly with respect to motorized vehicles, by designating this a special management area in 1975. Facilities for camping and picnic grounds were added to the Little Sahara Recreation Area in the mid 1970s and a staff was hired to implement the development plan (Figure 4). Little Sahara has short yet intense use periods. During weekends in spring, nationally sanctioned off-road vehicle (ORV) competitive events draw as many as 15,000 enthusiasts to the area. The sand dunes and varied topography also provide opportunities for pedestrian sand play and studies of plant/sand dune interaction (Figures 5 and 6).

The BLM has recognized the need for separating the various types of users at the sand dunes by closing off certain areas to ORV use. One portion of the dunes was designated as a natural area for dune-related studies.

Sand Movement

Concentration of sand in the dunes of the Little Sahara Recreation Area, and the effects that recreational use of the area may have on dune movement, may be better understood if several known characteristics of sand movement by wind are considered. There are three basic forms of sand grain movement called suspension, saltation, and surface creep. Fine sand and dust grains may be suspended by turbulent air once they have been lifted from the surface, that is, the fine grains fall more slowly than they would in still air. Suspension is particularly effective with smaller grains and is most effective in updrafts due to rising warm air (dust devils) and at the leading edge of wind gusts (Figure 7). Turbulent suspension of fine grains is not yet well understood. While it may result in transport of hundreds of miles, it is more commonly associated with shallow dust storms (Figure 8) and transport of a few miles.

Saltation is the process by which moderate sizes of sand grains move near the surface in a skipping or hopping motion. Once started in motion by wind forces strong enough to lift the grains from their settled surface locations, the grains collide with other sand grains upon falling back to the surface. The collisions result in the loosening of additional grains, and a rapid increase of saltating grains moving over the surface in low, long arcs. Saltation accounts for the primary motion of dune sands.

Surface creep results from the impacts on larger grains of moderate sizes of sand grains in saltating motion. The larger grains cannot be raised from the surface unless the wind is extreme, but the saltating grain impacts drive them slowly over the surface. The combined actions of saltation and surface creep lead to the ripples that are characteristic of dune surfaces (Figure 9). The ripples vary in spacing due to both wind speed and sand grain size, often indicating strong variation over a short distance (Figure 10). The sensitivity of the movement of the dune sand to small disruptions of the wind is illustrated in the ripple patterns around small plants (Figure 11), which serve to retard sand grain movement and therefore dune movement.

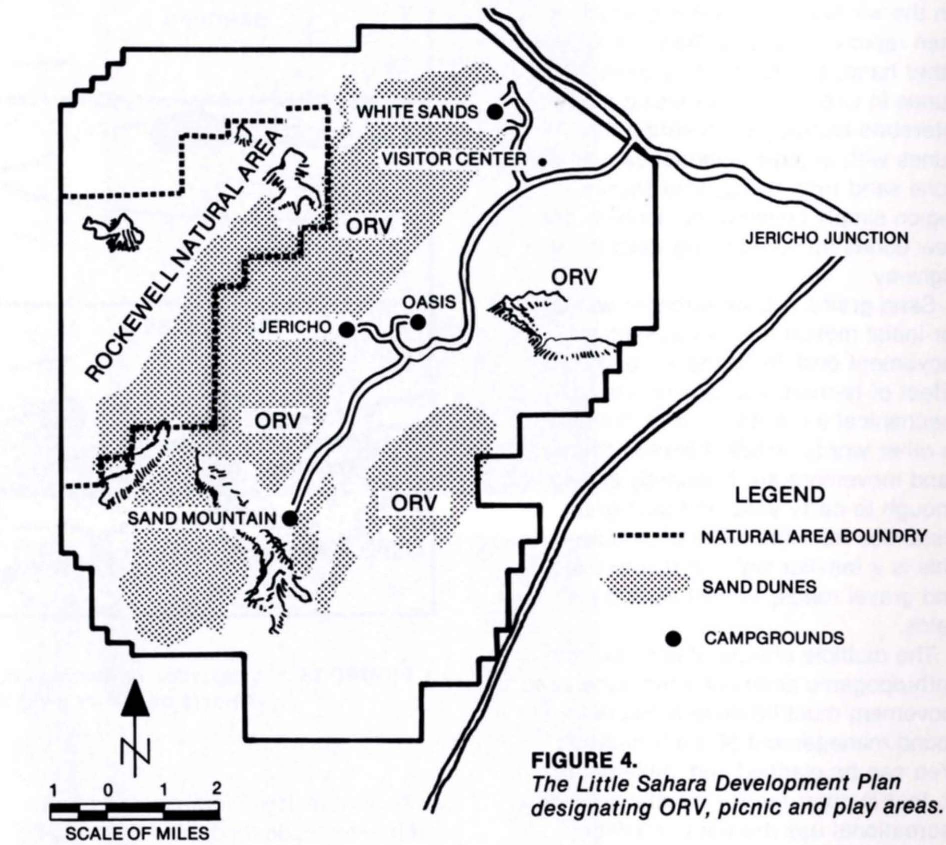

FIGURE 4.
The Little Sahara Development Plan designating ORV, picnic and play areas.

Dune Movement

Just as a small plant may deflect the wind and reduce forces on sand grains, so also will significant topographical features such as mountain ranges. As a result of deflection of the wind by a ridge or mountain range, the speed near the surface falls and is no longer sufficient to move the sand it has transported over more uniform topography. Figure 12 is an example of this effect. Numerous dune fields like this exist near mountain ranges throughout the west, such as the Great Sand Dunes in Colorado, the Death Valley sand dunes and Sand Mountain in Nevada (Figure 12). The dunes at Little Sahara appear to be of this type. Such dune fields are also affected by strong winds opposite in direction to the prevailing winds that brought the sand to the foot of the mountain, namely, storms and canyon or slope winds from the mountains. The counter movement may cancel dune movement by prevailing winds, once the dunes are near enough to the mountains.

One other important characteristic of sand dunes must be considered when appraising the effects of recreational use on dune movement. That is the formation and stability of the lee side of the dune, the slip face. As the dune sand builds to some depth from the surface, the wind separates from the sand surface (Figure 13), producing a relatively quiet wake region in which even light material is not blown away (Figure 14). The sand deposited on this dune slip face avalanches (Figure 15) to form the angle of repose for dry sand, that angle at which it will support its own weight. The slip faces of dunes cannot bear much additional weight without further avalanching to broaden the base of support (Figure 16) especially if the presence of slight ripples formed subsequently brings the sand to the limit of support (Figure 17).

The windward faces of sand dunes have much gentler slopes than the slip faces. Thus, avalanching due to traffic is greater in the direction of dune movement. This action may not actually lead to more rapid dune movement, however, for the wind must still supply the sand for movement of the dune as a whole over its advanced base. Increased roughness of the dune surface due to traffic on the windward slope may actually be more significant than the avalanching effect, if it results in stronger wind action on the exposed grains. In Peru a field of barchan dunes occasionally threatens to block a railroad line across the desert (Lettau & Lettau, 1978). The threatening dunes are easily destroyed by placing small stones on the windward dune slope, which is then rapidly eroded by the wind. On the other hand, an attempt to prevent sand dunes in Oregon from crossing a new interstate highway by covering the dunes with asphalt failed, because new dune sand from the upwind source region simply covered the asphalt, and new dunes marched along toward the highway.

Sand grains require stronger winds for initial motion than for sustained movement over the dune. An additional effect of recreational use results from mechanical initiation of sand movement. In other words, winds too weak to start sand movement are frequently strong enough to carry sand and dust great distances from the wake of vehicles. This is a familiar sight on unimproved and gravel roads, as well as in dune fields.

The multiple effects of physical and anthropogenic actions on the dune sand movement must be understood before sound management of the recreation area can be planned and implemented so that support facility maintenance and recreational use are not in conflict.

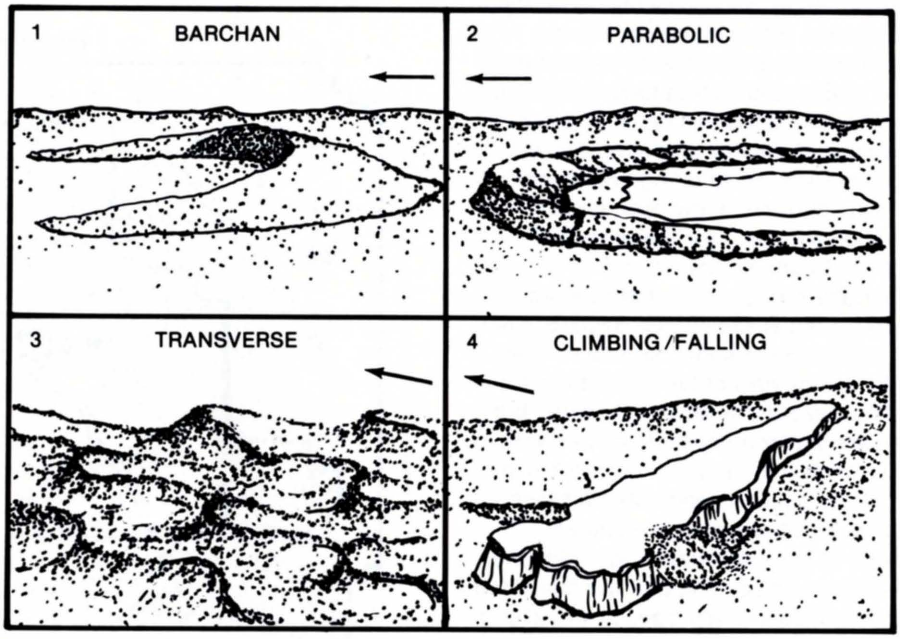

FIGURE 18. *Illustration of common dune formations at Little Sahara. Arrows indicate dominant wind direction.*

Sand Impacts on Developed Areas

Sand movement at Little Sahara is influenced by wind speed and direction, sand moisture content, vegetation, and topography. Many common dune types are found in this area including barchan, parabolic, transverse, and climbing/falling dunes (Figure 18, see also photos). Cold, wet winters result in water-saturated or frozen sand dunes, which remain stationary from November to April. Drier conditions in summer, combined with increased recreational use, account for much of the sand movement in the area. Accelerated erosion of the dune surfaces results from trampling of the crests of sand dunes and the disturbance of vegetation by foot and vehicle tracks. Particularly damaging to vegetation, and the microflora associated with it, are the concentrated uses occurring on trails and steep sand slopes during competitive events (Figure 19). Dune plants act as wind breaks, collecting wind-driven sand while microorganisms provide moist, nutrient-enhanced, stable microenvironments in association with plant roots. Disruption of the sand-binding effects that plants and microbes provide plays a role in subsequent wind erosion of sand during the dry season.

The rate of sand movement at Little Sahara can be estimated from a series of sequential aerial photos taken during the past 45 years (Figure 20). The relative northward displacement of the dune field with respect to fixed positions such as trees and drainage-ways has been minimal during this timespan. Although the sand dunes may change orientation or shape on an individual basis, the overall migration of the dune mass is hardly noticeable. Individual rates of barchan and transverse dune movement by fixed stake method and observations of sand migration at fencelines and around junipers has led to similar conclusions: The sand dunes are barely creeping forward.

The developed area of campgrounds, picnic facilities, and roads at Little Sahara are under threat of sand encroachment during periods of dry windy conditions. Outhouses, picnic tables, and firepits are often coated with sand, while fencelines protecting pedestrian sand play areas are continually being buried by shifting dunes (Figure 21). A better understanding of the process of sand movement and anthropogenic factors affecting it, is needed for future management considerations at the Recreation Area. One method to assess these factors would be to monitor the changes of a heavily used motorcycle site compared to the sand moved under conditions of foot trampling and a no-use control area. The enforced exclusion of ORVs from all areas is not consistent with pubic use of the area, but observations and sand trap measurements taken during heavy-use periods or during windstorms may provide estimates of their anthropogenic effects on sand movement.

Aerial view of Little Sahara reveals subtle shifting of the sands through time.

FIGURE 20
(a) 1939

(b) 1952

(c) 1977

Summary

From observation of sequences of air photos taken in 1939, 1952, and 1976, it is apparent that northeastward migration of the sand is slow. The question is will the current uses change the rate of sand migration. If so, what measures should be taken to reduce the migration to a minimum.

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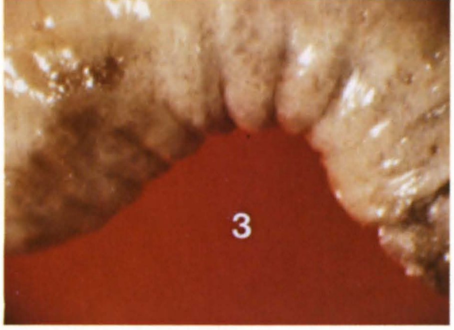
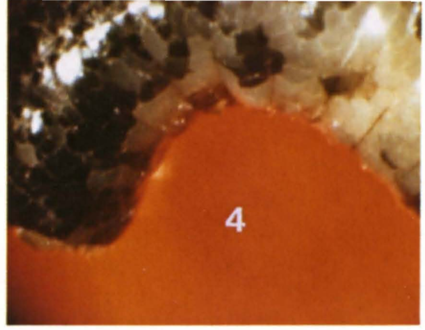
ABOUT THE AUTHORS

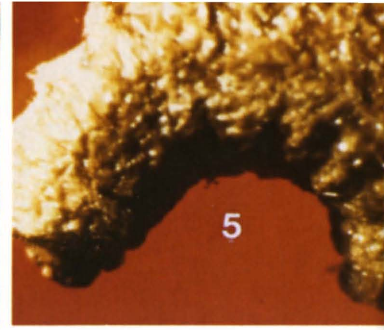
Bruce Chesler is a research assistant in the Soil Science and Biometeorology Department studying the eolian processes at Little Sahara for his thesis project.

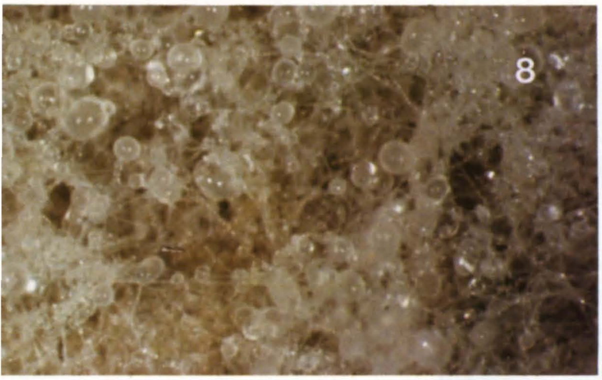
Leonard F. Hall is a research associate professor at USU. His primary research interests lie in micrometeorology and turbulence.

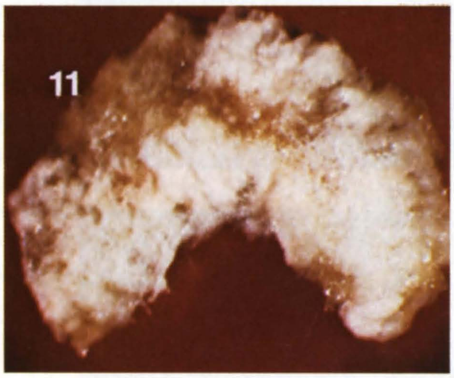
Alvin R. Southard is head of the Soil Science and Biometeorology Department at USU and professor of soil science. His field of specialization is soil classification and soil interpretation for use and management.











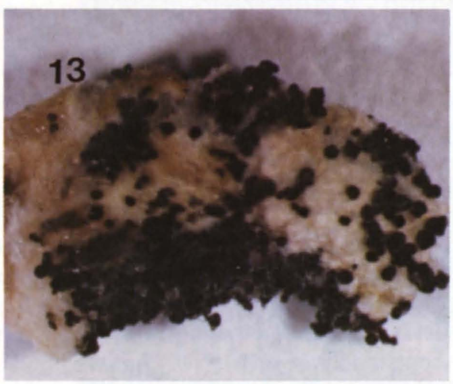


PHOTO CAPTIONS PHOTOS BY AUTHOR

*1. An adult Leafcutter Bee (**O. Lignaria**) on alfalfa.*

*2. Fourth instar larva of **M. rotundata** showing earlier symptoms of chalk brood induced by **A. aggregata.***

3. Fourth instar larva filled with grey-beige color of the myscelia of chalk brood.

4. Fourth instar larva with completely filled nutriocytes containing the developing spores.

*5. Dead larva filled with only vegetative brood of **A. aggregata**.*

6. A similar larva to that observed in Figure 4 but in 1/5 of this larva, the fungus was able to produce spores (dark brown color).

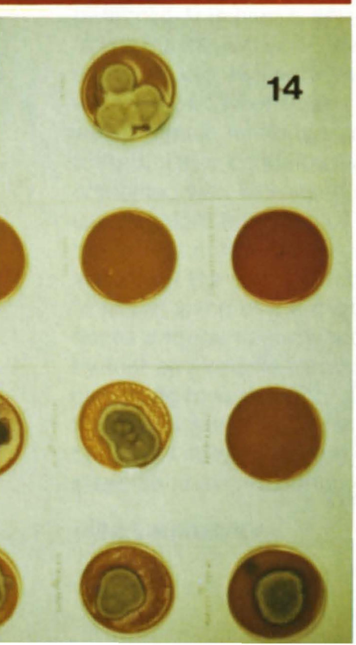
*7. A full grown leafcutting bee larva showing the typical symptoms of chalk brood induced by **A. aggregata.***

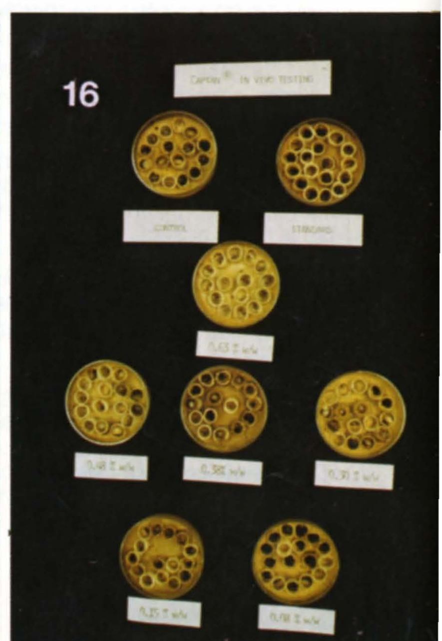
*8. **A. aggregata** growing on artificial media. The culture of this fungus on artificial media is a significant breakthrough in the study of chalk brood.*

*9. Two mating types of **A. proliperda** grown on artificial media. (Top row and right side.) Sexual development has occurred in the remaining four dishes where both types were brought together as evidenced by the dark midline indicative of cysts formation.*

*10. A leafcutting bee cell obtained Utah shows, upon removal of several pieces of alfalfa leaves that line the cell, that it had been parasitized by a fungus. The fungus was found to be **A. proliperda**, a relative of **A. aggregata**.*

11. Fourth instar larva of the leafcutting bee showing typical symptoms of infection by A. proliperda.





N. N. YOUSSEF

THE CHALK BROOD SYNDROME IN WILD BEES

Until the early 1950s the general attitude among alfalfa growers was to produce alfalfa seed as a catch crop depending on the right moisture conditions. The average seed production was about 150 pounds/acre and little was produced in the Northwest. With the development of new varieties of alfalfa resistant to insects and disease and with the interest in maintaining these varieties, high seed purity and, therefore, a reliable seed production program, was essential. The arid Northwest offered the answer where irrigation could be controlled and pollinators other than the honeybee were being managed. In this region, 7-10 fold increases in alfalfa seed yield/acre can be achieved with controlled irrigation, adequate pest management programs and effective pollination.

*12. A leafcutting bee cell (**M. rotundata**) infected with **A. proliperda** cut sagittally. The ascocysts outside the body are dissimilar to that of **A. aggregata** which produces its spores under the skin of the bee.*

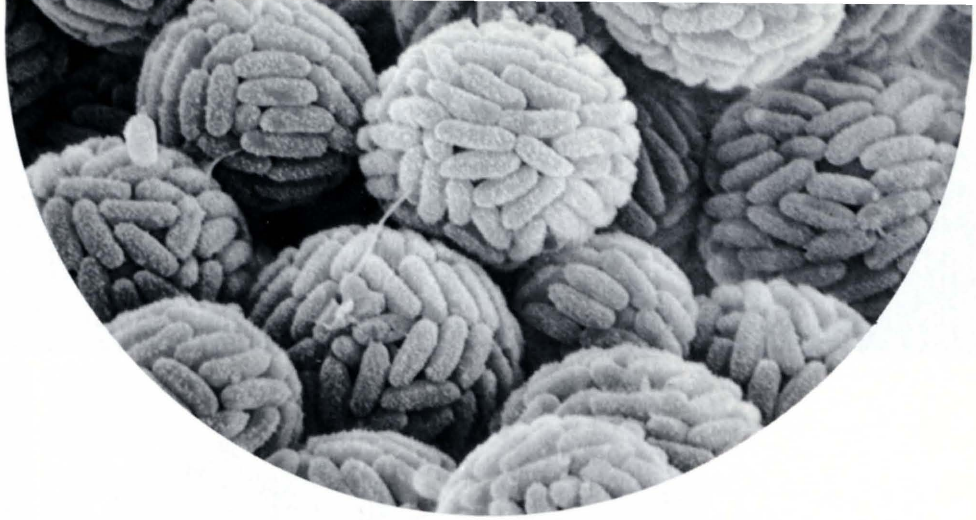
*13. A larvae of **M. rotundata** showing the typical symptoms of infection by **A. proliperda.***

14. This photograph illustrates the scheme used to determine the dosage of a specific fungicide prior to treatment of bees. Each dish contains a supporting media for fungal growth inoculated with spores to be tested. Each was sprayed with varying but specific amounts of fungicide; the totally orange ones being the most effective amounts.

15. Eggs isolated from nests were placed on artificial provision to screen for effective fungicide treatment.

16. Each dish contains the artificial provision (made of pollen and honey) which has been inoculated with fungal spores. A specific amount of fungicide was also mixed into the provision. Eggs were then implanted and surrounded with a piece of soda straw to simulate natural cells.

17. Close up of chalk brood disease growing in the control dish.



Within 15 years of its discovery in the West (Circa 1950), the leafcutting bee became the most predominant pollinator for alfalfa in the Northwest. Unfortunately, the increase in the population density of this species due to heavy demands by growers was not without problems.

Until the early 1970s, chalk brood disease in alfalfa leafcutting bees in commercial operations was only a curiosity. In 1974, a 20 percent loss of bees in Nevada was attributed to the disease, and within a few years had spread in many seed producing areas. The following Table 1 illustrates the incidence of chalk brood disease in the major area of alfalfa seed production.

Recognizing the severity of the problem, a considerable investment in research on the disease by producers, processors and universities in those states was undertaken.

In 1979, a cooperative regional research project was funded by the USDA to study the disease in an organized, coordinated, and systematic manner. With the rise of incidence of chalk brood in northern Utah and in the Delta area to over 30 percent, Utah State University initiated its program which is currently supported by the Agriculture Experiment Station and the USDA.

Our research objectives for the last four years have been:

1. To identify the causative agent(s) that induce the disease and to study its biology;
2. To culture these agent(s) on artificial media for future biological manipulation;
3. To conduct cross infectivity studies to determine host specificity; and,
4. To find a suitable chemical control measure for the fungus.

Chalk Brood Disease

What is chalk brood disease? The chalk brood disease or syndrome is defined by the presence of mummified larvae with an *Ascosphaera*-like fungus. This term was originally used to describe a disease that sometimes inflicts serious damage to honeybee broods. Only recently we have proved that other relatives to the honeybee fungus can cause the disease in the leafcutting bee.

In our laboratory we studied the life cycle of the fungus in the leaf-cutting bees and on culture media. Although the basic life cycle is similar for both species, the symptoms of the disease are quite different.

The first fungus we studied is known scientifically as *Ascosphaera aggregata*. Currently, it is foremost in destroying the larvae of the leafcutter bee. Larvae infected with this fungus are recognized as having a dark creamy, metallic brown or a brown-black color depending on fungal development. The color is actually the color of the dried hyphae or cysts that contain the spores beneath the integument (skin) of the larvae. Our studies revealed that for the infection to succeed, the developing larvae must feed on nectar or pollen contaminated with fungal spores. This route of infection is different than that of most fungi. Most fungi enter the host insect through a wound or through the respiratory system. This finding has enormous value for control measures. Depending on the temperature, the spores germinate and the fungal filament grows rapidly among pollen grains in the gut. The filament finally penetrates through and destroys a portion of the gut wall and spread throughout the body cavity. Within a few days, almost every tissue and organ is destroyed and are replaced by the fungus. Upon dying the larvae becomes translucent pink in color and gradually darken to reddish-brown. These color changes take place prior to the total replacement of larval tissue by fungal filaments. At this stage, the larvae are swollen and have an off-white color which is the color of the fungus. The fungus next begins its complicated sexual life cycle which results in the formation of millions of spores contained in sac-like structures beneath the larval integument. It is estimated that each infected larva, which expresses the disease fully, carries over one billion spores. These larvae can be recognized by their dull black color.

Causative Agent of Disease

The second aim of our investigation was to satisfy the four conditions known as Koch's postulates[1] in order to identify the causative agent of the disease. These conditions are:

1. The agent is present in every case;
2. The agent can be isolated in pure culture;
3. The pure culture can induce the disease in susceptible animals; and,
4. The agent must be present and recoverable from experimental animals.

After three years of intensive research and with the use of over 500 formulations of media, we were able to culture the fungus on artificial media, to induce the disease by using spores from our culture, and to recover spores from the experimentally infected larvae. Our results showed that without a doubt the fungus *Ascosphaera aggregata* is the causative agent of chalk brood disease in the leafcutting bee larvae in which fungal spores are produced under the integument in the leafcutting bee.

In the course of culturing *Ascosphaera aggregata*, we discovered a related fungus that also causes chalk brood but produces different symptoms. The fungus was identified as *Ascosphaera proliperda*. Until our discovery of the fungus, it was thought to exist only in Europe.

Instead of developing under larval skin, the fungus filaments (hyphae) penetrated through the skin and the sexual life cycle, which ended in formation of the spores, took place outside the larvae. The fungus has proved to be very pathogenic under laboratory conditions at the low dose of 3000/spore/bee and the incidence of the disease seems to be on the rise.

[1] Robert Koch is a famous German bacteriologist who, in 1876, proposed these conditions.

◄Over one billion spores like these can be dispersed from one bee cadaver. These spores are aggregated in spore balls which are contained in cysts that develop beneath larval skin.

TABLE 1. Incidence of chalk brood disease (average in %) in the leafcutting bee, 1974-1983.

	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Idaho	<1	8	10	40	32		no data		25	27
Nevada	20	35	50	50			no data available			25-29
Oregon	<1	3	12	40	28.4		no data		25	26.8
Washington	<1	1.5	5	20	22	24	33	30	26	32
Utah			no data		<1		about 32			

To determine the incidence of the chalk brood syndrome in other wild bees, an intensive survey was conducted in cooperation with Frank Parker and Philip Torcio of the Bee Biology and Systematics Lab., USDA, Logan, Utah. Rather than finding any of the four known pathogenic *Ascosphaera* spp. (*A. apis, A. major, A. proliperda,* and *A. aggregata*), we were able to isolate over 20 undescribed species from different bees.

Currently we are attempting to culture many of these fungi on artificial media as a basis for further biological and pathological studies.

Cross-Infectivity Studies

With the rapid spread of chalk brood at epizootic levels in the United States, Canada, South America, and Europe, the danger of spread of the disease to other pollinators, to say the least, is alarming. To determine the specificity of this group of fungi, a cross infectivity study was conducted in which we used another bee, *Osmia lignaria*. According to Torchio of the USDA Bee Biology and Systematics Lab, this bee has the potential for being the prime pollinator for almond, apple, pear, and many other fruit trees. In this study, we used six species of *Ascosphaera* (Table 2), including three undescribed ones that were isolates from *Osmia* spp.

Characteristics of the disease were expressed for all tested species; however, the rate of expression varied with different fungi and also with treatment. The lowest rate of infectivity (1.3-3.3) was recorded for *A. apis* when maintained at 20°C. The highest (100 percent) was *Ascosphaera* species #3 (see Table 2) when maintained at 30°C. In addition to demonstrating that *Osmia lignaria* can serve as a reservoir for the agents of chalk brood syndrome, our investigation suggests that temperature plays a role in expression of pathogenicity by these fungi. Similar investigations on other potential crop pollinators are in progress.

Since the bottom line in combating disease is to find a cure for the host or a control of the pathogen, we attempted the latter approach with some success.

For the fungus to succeed in inducing an infection, its spores must be ingested by the young larvae. Therefore, it is possible to control the fungus by either eliminating the spore from the environment or by destroying its spores or its vegetative stages in the gut. Since the first approach is under investigation at Oregon State University, we at USU selected the second approach.

Ten commercially and noncommercially available fungicides were screened for their potential as control agents for chalk brood when introduced into larval food.[2]

Over 7,000 eggs were removed from cells provisioned naturally and transferred to artificial provision made of pollen and honey. Known amounts of fungicides were mixed with provision that was inoculated with either *A. aggregata* or *A. proliperda* spores. Only Benlate® and Captan® were found to be promising as control agents without any appreciable harm to eggs or the developing larvae. A dose of 0.06 gm of Captan/bee was effective in reducing the incidence of chalk brood from over 60 percent to less than 10 percent without harming the developing larvae. Just by doubling this dose (0.12 gm/bee), however, 66 percent of the developing larvae died before maturation. Although these are encouraging results, there are still ample problems (such as adequate delivery system) which need to be solved before routine application can be recommended.

[2]These were Terraclor, Manzate 200, Benlate, Captan, Vitavax with Captan, Mertect 360 WP, Bay KWG 0519, Bay Meb 6447, CGA 64251 1OWG and CGA 48988/CGA 64251 (7.5:1).

TABLE 2. Spore size of six *Ascosphaera* spp. used in the cross-infectivity study.

Pathogen	Size of spore
Ascosphaera. n. sp. 1	4.50 ± .27 × 2.4 ± .6
Ascosphaera. n. sp. 2	11.70 ± .68 × 3.70 ± .21
Ascosphaera. n. sp. 3	30.19 ± 1.13 × 7.14 ± .75
Ascosphaera. proliperda in vitro	5.3 ± .36 × 2.56 ± .19
A. proliperda (from Canada)	5.3 ± .36 × 2.56 ± .19
A. apis in vitro	3.6 ± 0 × 1.7 ± .12
A. aggregata (from Canada)	4.83 ± .1 × 2.4 ± 0

In conclusion, Utah State University has contributed heavily toward the understanding of the chalk brood syndrome. More research is needed, however, to utilize basic knowledge gained from our project and those of other states in order to combat this disease.

ACKNOWLEDGEMENT

My sincere thanks are due to all of those who have, to this point, helped with the project. These include in alphabetical order: Ron Bitner, Catherine Cox, Penny Hansen, Bill McManus, Bill Nye, Ingrid Reynolds, Frank Parker, Carl Roush, Nancy Sorensen, Vince Tepedino, Phil Torchio, and Glen Trostle. For details of the project, consult the publication list.

ABOUT THE AUTHOR

Nabil N. Youssef, professor of Biology, received his BS from AIN-Aham University, and his MS and PhD from USU. His major interests is in developmental biology, Neurobiology and pathology of Invertebrates and Fish.

N. K. VAN ALFEN and P. DRYDEN

PHOTOS COURTESY OF AUTHORS

PINTO BEAN ROOT ROT

PHOTO CAPTIONS

1. *Healthy bean plant showing normal hypocotyl.*

2. *Red discoloration of hypocotyl infected by* **F. solani** *f. sp.* **phaeseoli.**

3. *Hypocotyl symptoms of bean root rot caused by* **Fusarium solani** *f. sp.* **phaeseoli**. *The numbers represent the disease index (DI) value assigned for the relative severity of hypocotyl disease symptoms. A DI of 0 represents no disease symptoms. Increasing DI numbers represent increasing disease symptoms as shown.*

4. *Typical foliar symptoms of a bean plant infected with* **F. solani** *f. sp.* **phaeseoli.**

5. *USU research plot in the Four-Corners region. The soil was fumigated to eliminate* **F. solani** *f. sp.* **phaeseoli** *from the soil. This is a useful experimental method to control the disease, but much too expensive to use by growers.*

6. *One of the authors (Paul Dryden) working on the fumigation plots.*

Anasazi ruins, deep arroyas, red arches, and pinto beans are all part of the mixture of tradition, magnificant resources, and fragile balances that are constantly encountered in southeastern Utah. The Anasazi ruins remain as the greatest reminder of the limitations and balances that operate in this area. A once great culture based upon a flourishing agriculture, of which beans were an important part, disappeared from this region before our history writers could chronical their decline. Declining agricultural productivity undoubtedly played a role in the disappearance of this culture.

Many factors can contribute to the decline in productivity of a crop. In a region such as southeastern Utah, water is the greatest limitation on crop yields. It is not unreasonable to assume that lack of adequate water eventually led to the decline of the Anasazi culture.

Water can be unavailable to a plant even if it is plentiful. It is, thus, ironic that one of the factors limiting the profitable cultivation of pinto beans in the arid Colorado plateau area is a plant disease that destroys roots, and, thus, the ability of plants to absorb the precious water from soils.

Beans grown under dryland conditions, as they are on the Colorado plateau, produce relatively low yields. Economically, there is not much of a margin, thus when root diseases rob the grower of up to 25 percent of his potential yield, growing beans can change from a profitable to an unprofitable venture. The limited yield of dryland crops also reduces the number of things that can be done economically to control a disease such as root rot. Factors such as this root disease can frequently tip the balance in crop productivity to the point where continued cultivation of the crop becomes infeasible. Thanks to trucks that bring food, the survival of residents of southeastern Utah are not dependent upon healthy beans, but the disease does "eat" potential profits of bean growers. And, unlike the Anasazi or our not very distant forefathers, we no longer have the option of moving on when the balance tips against the profitability of farming a particular piece of land.

We have been attempting to better understand the biology of root diseases of pinto beans under dryland conditions. If the option no longer exists to move on, then management of the land must be learned so that it won't be abandoned. There are three questions raised which were important to learn about this disease in southeastern Utah: (1) Is it native to our soils? (2) Is it one disease or a complex of diseases? And, (3) Can we provide plant breeders with information that can be used in developing resistance to this disease?

The disease found to be responsible for most of the losses in the pinto bean fields is caused by a fungus with the name *Fusarium solani* f. sp. *phaseoli*. The most characteristic symptom of the disease (other than sick-looking plants) is a reddish dry rot that develops in the stem of the plant at, or below, ground level. By the end of the growing season, frequently, the fungus has rotted almost the entire stem of the plant. Evaluation of the relative resistance of plants by assessing the size of this decayed region is the most common practice in plant breeding programs. It is generally felt that the plant stress caused by the pathogen is due to girdling of the stem, preventing free movement of water.

The pathogen causing this disease goes by the same name as one common in most soils, but differs in that it can attack bean plants. So specialized is this pathogen that it cannot attack other plants. It was thus unlikely that this pathogen would be found in soils that have not previously been sown with beans. This was confirmed when virgin fields that had recently been converted from juniper stands to bean fields were surveyed. Beans growing in these fields were generally free of disease. A few scattered plants were found that were infected, suggesting that the disease was introduced very recently into the field. The most likely source of the disease is contaminated seed or mud carried from infested fields on farm equipment. Unfortunately, once the pathogen has been introduced into the soil, it can survive there for many years, even if beans are no longer grown.

The girdling of the bean stem by the fungus has been used to assess the amount of damage caused by the pathogen. Obviously, if the stem is completely girdled, neither nutrients will be able to move from the leaves to the roots nor water and mineral nutrients from the roots to the leaves. Plants, however, have a large excess capacity within the vascular system, so they can withstand considerable damage to their stems without being adversely affected. A study was conducted to measure the effect of stem damage on the plants' water status and yield under the assumption that if the fungus was doing sufficient damage to the stem, the plant would be stressed for water which would result in lower yields. The data presented in Figure 1 indicate that there was no relationship between yield and the amount of stem damage as represented by the disease index (0 = no disease, 5 = totally girdled stem). As expected, however, there was a high correlation between plant water stress and yield (Figure 2).

Our data suggested that the visible damage caused by the pathogen although severe in appearance, did not seem to induce water stress in the plant. If the lesions on the stem were not causing water stress, then perhaps the site actually affected by the pathogen was the plants' feeder roots. An investigation was made of this possibility by determining whether propagules of the pathogen were prevalent in the soil at the same depths as the roots. Also tested were the plant roots to determine the numbers of sites on the roots colonized by the pathogen. Figure 3 shows the relationship between root density, numbers of fungal propagules, and numbers of sites on roots colonized by *F. solani* f. sp. *phaseoli* per centimeter of root with root depth in the soil. Most propagules of the pathogen are in the upper 45 cm of the soil. The pathogen propagules are evenly distributed throughout the upper 45 cm of soil and the roots are uniformly infected by the pathogen at these depths. The pathogen clearly is colonizing a substantial proportion of the plant's roots.

In some additional studies, the soil water availability was determined at different depths during various times of the growing season. In July about 20 percent of a plant's roots were below 60 cm and about the same proportion of the available water was present at this depth. Later in the season, however, as the crop was maturing, the stratum of the soil containing these 20 percent of the roots now held almost 50 percent of the available water. We feel that the statum from 45 to 60 cm deep is where the pathogen can be particularly damaging to the plant late in the growing season. At this time, 50 percent of the available water is present in this stratum, yet only about 20 percent of the plant's roots are there. The plant is thus very vulnerable to damage if these roots are attacked by the pathogen. Water extraction ability could be severely affected by the pathogen at a time when water has become very limiting to the plant. We have not yet collected enough evidence to confirm our hypothesis, but the data we have collected indicate that in our future studies we must concentrate on a small proportion of the plant's roots in assessing how the pathogen is able to stress the plant.

We feel that the stem cankers do not significantly contribute to the damage caused by the pathogen, and thus should not be used to assess resistance to the pathogen in plant breeding studies. A better criterium for selecting plants in breeding trials would be total yield responses. If the plant shows resistance, it will yield better than susceptible plants. Unfortunately, the evaluation of root lesions is too tedious to use in any breeding trials.

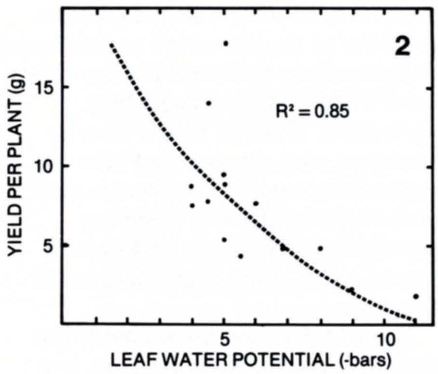
Plant breeding trials in which resistance to a specific disease is sought can be confused if other diseases showing similar symptoms are also present. Although the root rot of bean is by far the most common and serious disease of pinto beans, we found that a second disease exhibiting similar symptoms was also present. This second disease is caused by the bacterium *Corynebacterium flaccumfaciens* which causes a wilt symptom. This bacterium is most commonly transmitted by infected seed. Thus, if it becomes a serious problem, it should be controlled by using disease-free seed. The identification of this second common disease will prevent confusion in plant breeding trials in the area.
free seed. The identification of this
second common disease will prevent confusion in plant breeding trials in the area.

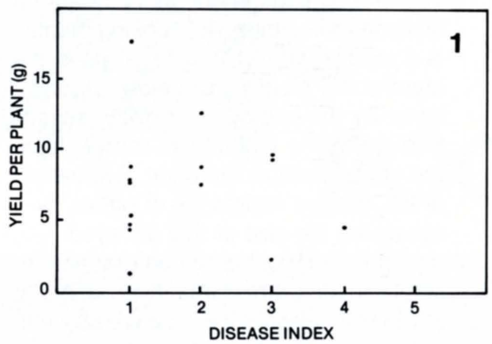
The work that we have done in southeastern Utah trying to understand the root rot of pinto bean under dryland conditions has not resulted in an immediate control method. Rather, we have identified aspects of this disease unique to our conditions that should be helpful to plant breeders attempting to increase the resistance of local varieties to this disease. Considering the economics of dryland agriculture, use of chemicals, even if effective ones were available, would not be economically feasible. Incorporation of disease resistance into new varieties of beans is the most reasonable approach to reducing losses caused by this disease. It is also possible to prevent the disease from being introduced into virgin bean fields if some care is exercised.

ABOUT THE AUTHORS

Neal K. Van Alfen is a professor in the Department of Biology at USU. His major interest is in biochemistry and physiology of plant host-pathogen interactions of the wilt diseases, mycoviruses, and field and forage crop diseases. He received his BS and MS from Brigham Young University, and his PhD from the University of California, Davis.

Paul Dryden is a former graduate student in Biology at USU. He received his BS from Humboldt State College and his MS from the University of California, Davis.





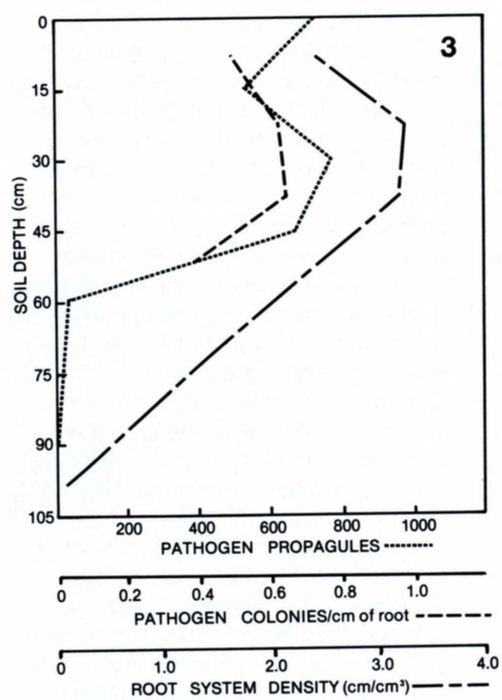


FIGURE 1
Relationship between bean yield and disease index. See photo number 3 for relative amount of stem damage for each disease index number.

FIGURE 2
Relationship between bean yield and water stress as measured by leaf water potential at 10 A.M.

FIGURE 3
Relationship between soil depth and root system density, pathogen propagules, and pathogen colonies/cm of root.

W. A. BRINDLEY

UNITY AGAINST RESISTANCE

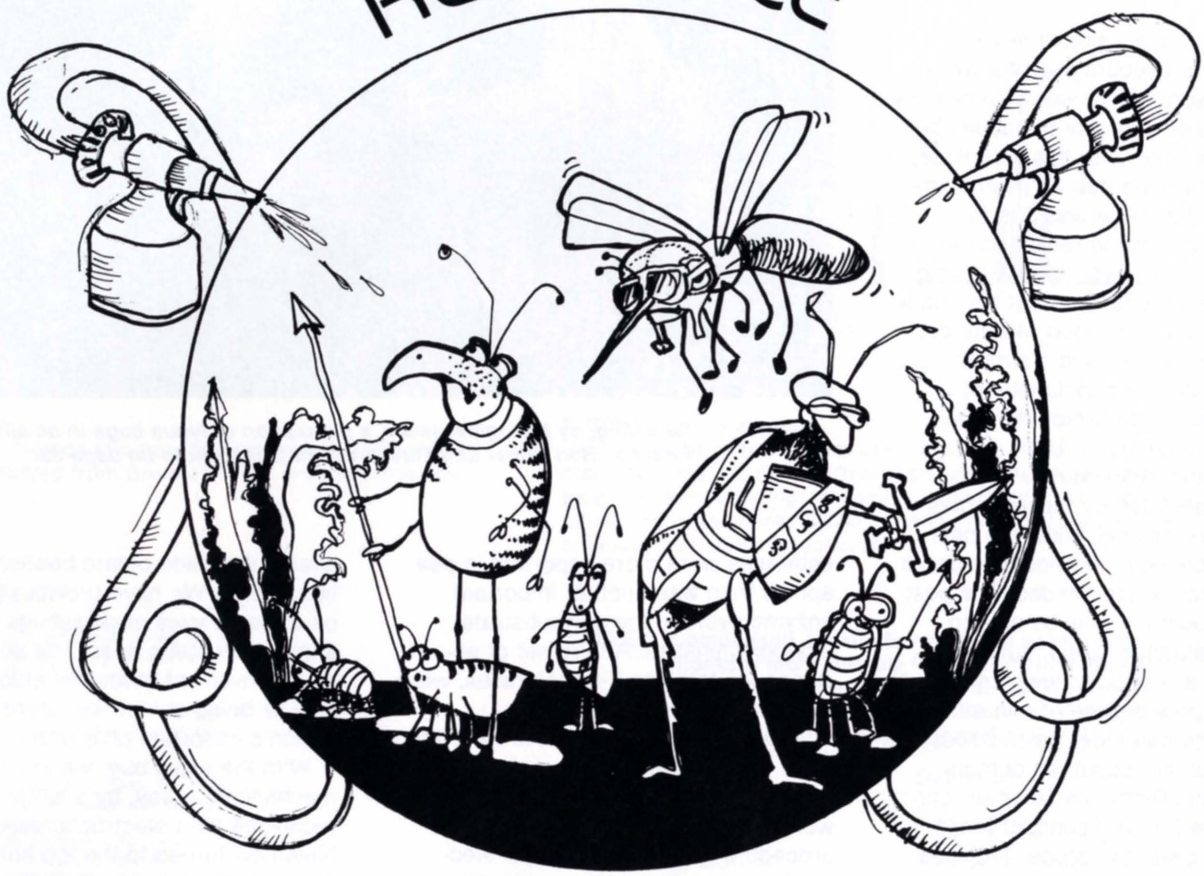


Illustration by Don Carter

DDT, a very effective insecticide, failed to control certain housefly populations in Denmark after a few seasons of use. Twenty-seven years later, 16 other insecticides had been employed against Danish housefly populations, some holding their effectiveness for a substantial period of time, others failing quickly (Keiding, 1977). This is an example of resistance to insecticides.

In 1970, records showed there were 224 resistant species of insects and arthropods for a total of 313 cases. By 1980, the total of resistant species equaled 829 (in Georghiou and Saito, 1983). Resistance is now known, although less frequently than for insects, in weeds to herbicides, plant diseases to fungicides, rats to rodenticides, and animal parasites to antihelminthics. Disease-causing bacteria may also become resistant to antibiotics. Soil bacteria may adapt by resistance-building mechanisms, to a rapid degradation of soil residues of certain insecticides.

An effective pesticide is a precious agricultural resource. It must not be squandered. Each new insecticide eventually emerging from chemical screening programs is very costly. In Japan, for example, a new commercial pesticide may cost $10,000,000 and 8-12 years of effort. United States figures are probably comparable. The farmer, expecting to achieve effective pest control, wastes effort, time, and money if the target pest has become resistant. Worse, the farmer may simultaneously depress populations of beneficial insects that help keep his pests in some degree of control or that pollinate his crops. There may not be alternative registered insecticides for his use.

Agricultural agencies operate resistance surveillance programs. One of the most successful has been that of the World Health Organization (WHO, United Nations) in testing for insecticide-resistant mosquitoes. The success of the WHO program has depended upon, in part, development of a rapid, simple test to find resistant mosquitoes. In general, agriculture has not followed the WHO model, and, therefore, has too few simple tests for resistant pests.

In 1972, for example, the Entomological Society of America (ESA) published a procedure for testing for insecticide resistance in alfalfa weevils. It seemed too complex to be of direct use in the field and we substituted a simple contact bioassay (Table 1). Rather than being confined to the laboratory as is the ESA procedure, our bioassays in small glass vials were easily applied in the field (Figure 1).

The results of our simple field bioassay were encouraging. We were able to measure alfalfa weevil sensitivity to insecticides—not only the adults but the larvae as well. With this technique, we could determine that an insecticide failure near Huntsville was due to misapplication—not to resistance to insecticides. This saved research time and reassured the farmer that his alfalfa weevils had not developed resistance.

We have recently used a similar bioassay to identify populations of resistant lygus bugs, which damage alfalfa seed, near Delta, Utah, and Caldwell, Idaho. Several new needs have been identified by these studies.

FIGURE 1 *Sampling, by biological assay, a population of lygus bugs in an alfalfa seed field (Dr. Ron Bitner and Teresa Brewer). See photo on page 59.*

Techniques that will allow the pest manager, working in individual fields, to detect resistance are needed. The pest manager should not only be able to measure resistance levels, but also determine if a particular resistance level will mean a poor degree of control. Bioassay data can meet these needs. A pest-management scout, as demonstrated by Ann Blom one summer, can plan, prepare for, and conduct these bioassays if given the proper facilities and training.

In short, the producer and pest manager may become allies to the entomologist and toxicologist in analyzing resistance. Figure 2 suggests relationships that are appropriate and, in most cases, have proved themselves realistic and workable.

One of the critical steps in resistance management is identification of the mechanism of resistance. By a system of simple calculations developed largely at Utah State (Brindley and Selim, 1984), we can translate bioassay data into estimates of the relative importance of enzyme systems that insects use to detoxify insecticides. Studies of pea aphids helped to illustrate the concepts in Figure 2.

By a series of bioassay and biochemical experiments, we identified major enzyme systems that pea aphids use to manage paraoxon, an organophosphorus insecticide never used in the field but useful for biochemical interpretations. Figure 3 shows that esterases were more important in pea aphids than was another important enzyme system, the polysubstrate monooxygenases. A third set of enzymes, glutathione-S-transferases, were found not to be important.

After we learned esterases were the most important in the pea aphids' management of paraoxon (Figure 3), we were able to develop a laboratory procedure (polyacrylamide gel electrophoresis) with which we identified individual aphid's detoxication abilities. Electrophoresis allows us to sample aphids to determine if measurable portions of the aphid population have characteristics of insecticide-resistant aphids. This prospect has important consequences for resistance management.

The proportion of resistant individuals in a population may be placed into computer programs that have been developed elsewhere (University of California; Texas A&M University; CSIRO, Australia) (see Georghiou and Saito, 1983). The computer's models predict how resistance will change according to factors that we can introduce, or how the insects will behave. Estimates of the frequency of resistant insects will be especially important as we trace the efficiency of steps used to correct a resistance situation.

We have completed or are now conducting similar work with lygus bugs or spotted alfalfa aphids that infest alfalfa, Colorado potato beetles, and house flies. We have previously worked on three species of grassbugs and alfalfa leafcutting bees. The bees served as a convenient model for studies, as well as being one of the Intermountain region's important pollinators.

With the lygus bug, we are close to a mechanistic assay, by a simpler technique than electrophoresis, and have now turned to the left hand side of Figure 2. Spray trials of trichlorfon for lygus bugs have been conducted along with the bioassay. By correlating both experiments, after the 8-hour bioassay test, we could tell a farmer if trichlorfon will control the lygus bugs affecting his seed crop. We are continuing these experiments to determine just how specific that prediction can be.

Bioassay data are of central importance to the coordination of resistance management. Training in toxicology is required to interpret them. To provide that training, we have given Utah State University students access to a course, including substantial field experience, in Pesticide Resistance.

An integrated resistance management scheme, therefore, seems to be within reach. We can generate many more useful data than we ever realized by simply turning to the field, making laboratory techniques applicable in the field, and enlisting the farmer in the battle against the resistance problem.

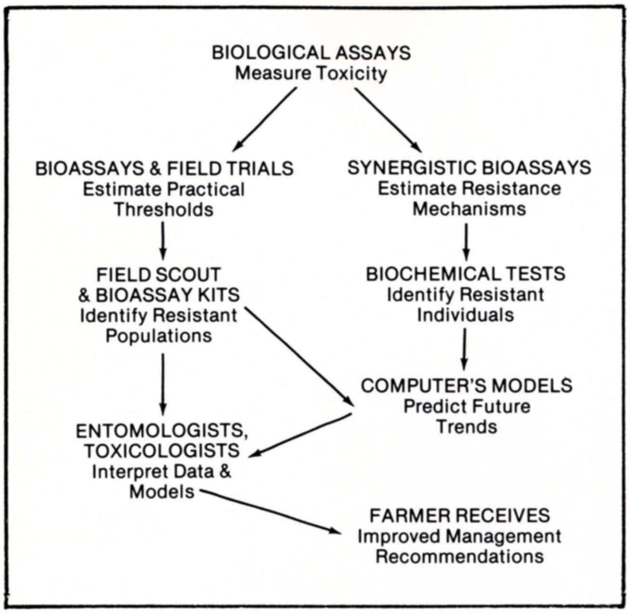


FIGURE 2
Integration of steps in a possible resistance management program (adapted from Brindley, 1982, with permission).

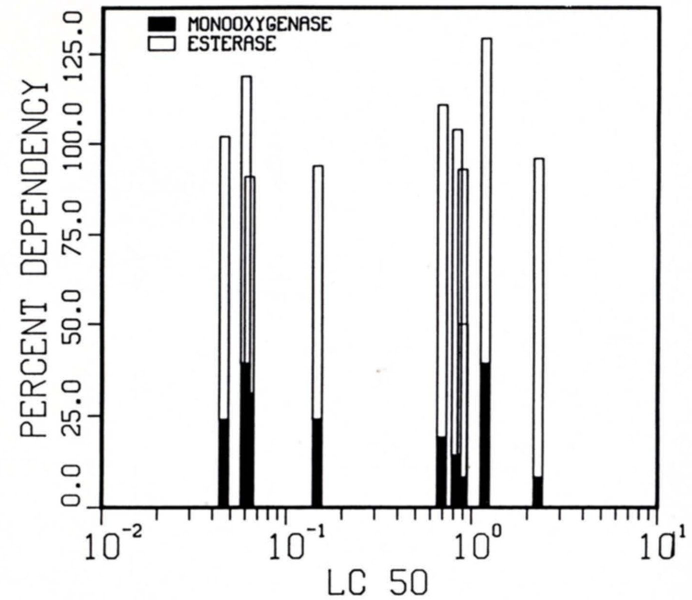


FIGURE 3
Relative roles of two detoxication systems (esterases and monooxygenases) in 10 different populations of pea aphids as estimated by biological assays conducted in the field and as related to tolerance (LC50 in nanograms of paraoxon per bioassay vial) to an insecticide.

TABLE 1. Comparison, for alfalfa weevils, of a standardized bioassay more suitable for confirmation than detection of resistance (Roussel et al., 1972) and a bioassay designed for rapid assessment of insecticide responses in field populations Brindley, 1975).

Confirmation	Detection
Collect mature larvae	Add insecticide to kit of vials
Feed fresh alfalfa	Collect adults or larvae
Keep at 20 ± 2 C	Put 5 each in vials (a)
16:8 photoperiod	Record mortality
Keep at 20-40% RH	Analyze by linear regression
Allow to pupate	
Collect adults at emergence	
Treat 3 days after emergence	
Treat with 1 ul per insect	
Feed fresh alfalfa	
Use 300/test	
Record mortality 1, 2, 3 days	
Analyze by probit analysis	

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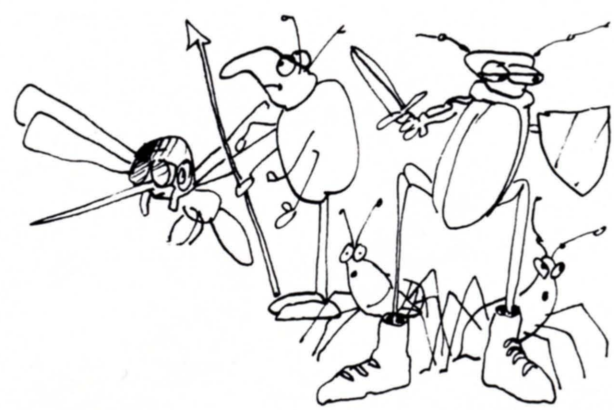
ABOUT THE AUTHOR

William A. Brindley is a Professor of Entomology in the Department of Biology, College of Science, whose research emphasizes comparative and agricultural toxicology.



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